1971

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Louis Allen Liljedahl
Iowa State University

72-5224

LILJEDAHL, Louis Allen, 1929-
EFFECT OF FLUID PROPERTIES AND NOZZLE PARAMETERS ON DROP SIZE DISTRIBUTION FROM FAN SPRAY NOZZLES.

Iowa State University, Ph.D., 1971
Engineering, agricultural

University Microfilms, A XEROX Company, Ann Arbor, Michigan

Effect of fluid properties and nozzle parameters on drop size distribution from fan spray nozzles

by

Louis Allen Liljedahl

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of The Requirements for the Degree of DOCTOR OF PHILOSOPHY

Major Subject: Agricultural Engineering (Field Power and Machines)

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1971

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I. INTRODUCTION

As civilization has advanced, man has attempted various new means of improving the efficiency of his food production. This includes methods of controlling certain pests, which either compete with man for the consumption of the food he is growing, or compete with food plants and animals for nutrients and water. It is natural that man, long interested in alchemy and the mysterious effects of chemicals, would try to use chemicals for the control of these insects, weeds, and other organisms. As early as 1,000 B.C., Homer spoke of "the pest averting sulphur", and in the 18th century certain chemicals were recommended for preservation and fungus control (McNew, 1959). Routine use of pesticidal chemicals started shortly after the discovery of Bordeaux Mixture, by Millardette in the 1880's, for the control of downy mildew of grapes (Horsfall, 1956). These chemicals came to be used in increasing quantities, particularly in high value agricultural crops.

Use of chemicals for pest control in agriculture expanded rapidly after 1945. At that time, the phenoxy-alliphatic herbicides and the chlorinated hydrocarbon insecticides were introduced for general domestic and agricultural use. These chemicals were inexpensive, effective in very small dosages, and had low mammalian toxicity. The success and widespread adoption of these chemicals triggered a search which still continues for other chemicals which might have similar or other pesticidal properties. A large number of such chemicals have been found and produced commercially. In normal agricultural production today in the United States, a great amount of such chemicals are ordinarily used (Strickler and Hinson, 1962).

A. Loss of Control of Spray

Many of these pesticide chemicals are liquids, or can be emulsified or put into solution with inexpensive commercial solvents. In this form it is common to apply them to plants, animals, or the soil as a spray. Projected spray will, with relatively little special effort, produce a moderately uniform deposit upon rather irregular objects. This characteristic is exploited when paint is sprayed or pesticides are sprayed. However, sprays are not easy to control with a desirable degree of predictability. That is, only a portion of the sprayed material is deposited upon the intended target. The remainder is deposited some place where its presence is considered undesirable or wasted.

1. Effect of drift

The first type of lost material which became an object of concern was the undesirable deposit, called drift. Drift of a herbicide onto a crop which is sensitive to the chemical may kill the crop. Drift of other pesticides onto other crops for which there exist no legal tolerance for residues may result in the crop being unmarketable. Either type of drift may cause large economic damage, and cause individuals responsible for the drift in turn to be sued for compensation for the damage. Akesson and Yates (1961), for example, showed that even under good weather conditions, spraying upwind of a field of alfalfa hay closer than 600 feet with 1.5 lb/A of DDT would result in deposits of chemical on the hay which exceeded legal limits for marketing.

2. Deposition efficiency

Another type of lost material is the waste caused by poor deposition efficiency on the target. Bowen et al. (1952) measured the proportion of chemicals deposited on target plants by conventional spraying and dusting equipment. They found the deposit to be quite variable, but it was most frequently between 5 and 15 percent of the total amount used. Reeves et al. (1967) measured the proportion of spray deposited on simulated cotton plants, compared with alternative application methods using a rotary brush. They found the average proportion of chemical deposited on the simulated plants by spray to be 5.1 percent of the total used. Since large amounts of chemical are used in agricultural production each year and a major proportion of these chemicals are applied by spraying, this poor efficiency represents a considerable loss. Strickler and Hinson (1962) indicated that $462 million is spent annually for chemicals used in agricultural spraying. Stanton and Dominick (1963) reported that cost of spray materials alone represented 31 percent of the total cost of producing apples for fresh market in eastern United States.

3. Atmospheric pollution

Some of the spray becomes airborne for sufficient length of time to cause a health hazard, and this is another type of lost material which is of concern. Argauer et al. (1968) measured the deposit in the swath and the deposit up to one-half mile downwind resulting from sprays applied by aircraft at conventional rates (37 l/ha) and at an ultra low volume rate (2.4 l/ha). The amount of chemical recovered within one-half mile of the point of release by deposit on the ground averaged 52 percent of the total, and in one test was 18 percent. The most plausible hypothesis to account for the remainder of the spray is that it still remained airborne. If this is so, the airborne spray must contain an appreciable fraction of droplets in the one to five micron diameter range, which are known to be respired into the lungs and be retained in the aveolar tracts, where the material is readily absorbed into the blood (Davies, 1961). Seven percent of the pesticide related occupational disease incidents reported by Kleinman et al. (1960) were respiratory illness, which indicates that airborne spray may be a health hazard. Thirty-three percent of the incidents reported by Kleinman et al. were classified as systemic poisoning, of which a portion may also have been caused by inhalation of spray.

To improve the control of spray by application equipment, exploitation of a number of forces known to affect small particles has been investigated by a number of workers. Aerodynamic forces, electrostatic forces, and thermal gradient forces have been applied to cause changes in the trajectories of spray droplets. Carleton et al. (1960) showed that the relative magnitudes of these forces are directly dependent upon the diameter of the droplet being subjected to the force. Normal spray from equipment currently in use has a widely variable distribution of droplet sizes. These distributions are log-normal in general form, and result in a 20-fold or greater range of droplet diameters from a single piece of application equipment. Because of the wide variation in droplet diameters present, even a careful application of these forces to conventional sprays will result in a wide variation in droplet trajectories, frustrating the attempt to improve the control of the spray. A more detailed review of this problem by Courshee (1961) and Carleton et al. (1960) indicated a need for improved uniformity of spray droplet size before much progress could be expected in controlling droplet trajectories and the resulting deposition of spray.

B. Biological Effectiveness

In addition to the proposed value of more uniform spray for better control of pesticide spray deposition, a number of workers have reported evidence that pesticide application in certain droplet sizes may have a greater biological effect than when applied in another droplet size. Early work with modern insecticides by Yeomans et al. (1949) reported that the most effective diameter for DDT spray for control of mosquitoes was approximately 12 microns. Davis et al. (1956) tested fine, medium, and coarse sprays of DDT from aircraft for control of the spruce budworm. They reported highest mortality was obtained with the medium spray, which had a mass median diameter of approximately 150 microns. From probit analysis curves constructed with their experimental data, they estimated that 95 percent mortality could be achieved with a 50 percent reduction in the amount of pesticide used if the optimum droplet size spray was used for the application. The experiments of Davis et al. were done with sprays having a wide range of droplet sizes. Thus the droplet size distribution of all the sprays used overlapped to a considerable extent.

Hedden (1961) conducted an extensive series of experiments testing the effectiveness of disease control chemicals and insecticides on several vegetable crops using sprays having mass median droplet sizes from 100 microns to 500 microns. The results of these tests indicated that little if any variation in control could be attributed to differences in droplet size of the sprays used. This experiment, like the work of Davis et al. (1956), used sprays having a wide range of droplet sizes and considerable overlap existed for the various size distributions used in the tests. This may have caused a loss of discrimination in the experiments.

Hartley and Brunskill (1958) conducted controlled laboratory experiments and showed that spray droplets in the range of 100 to 300 microns will bounce from the leaf surface of crop plants without retention if the surface tension of the droplet is high. Droplets smaller than 100 microns had 100 percent retention. Ennis and Williamson (1963) showed that the herbicidal activity of several chemicals increased as the droplet size decreased, when the volume of liquid used was low. Bengtsson (1964) conducted experiments on other crop and weed species with several herbicides and reported a similar effect of droplet size.

Workers investigating the use of ultra low volume spray methods have speculated that droplet size effect may be responsible for its increased effectiveness (Skoog et al., 1965). Himel and Moore (1967) inferred from particle size measurements made on insect larvae killed during actual field spraying operations that the bulk of insect deaths could be attributed to pesticide delivered as particles less than 50 microns in diameter. Burgoyne and Akesson (1968) and Kilpatrick (1967) reported that spray with a certain droplet size was most effective for control of mosquito larvae, but no supporting data were presented. Mount et al. (1968) reported the results of field experiments in which greatly reduced total dosage of pesticide produced satisfactory kill of mosquito adults when sprays of droplet size ranging from 6.4 to 10.8 micron diameter were used.

C. Recent Proposed Improvements

Since the suggestion by Carleton et al. (1960) and Courshee (1961) that more uniform droplet size might result in better controlled spray, a number of attempts have been made to produce more uniform spray by various means. Kirch et al. (1958) proposed that a spray liquid could be thickened by making it into an invert emulsion. Such an emulsion could have viscosities up to 10,000 centipoise. Kirch et al. distributed this material in the field using a spinning drum with nozzles or other orifices on its periphery. The resulting spray was quite coarse, having mean droplet sizes of several millimeters. It was claimed that a reduction in drift of the spray resulted. This was most likely due to the general increase in droplet size rather than increased uniformity.

Douglas (1968) proposed a design of a nozzle with a multiplicity of orifices on the periphery of a cylinder which oscillated radially approximately 0.4 radians. No data have been published on the uniformity of spray produced by such a device. The Dorman Sprayer Co. in Cambridge, England (National Institute of Agricultural Engineering, 1958) proposed that a hollow cone spray nozzle operated at 10 lbs per-square-inch would be a useful system for producing uniform spray droplets. Tests were conducted to show the lower proportion of spray droplets less than 100 micron diameter compared to a conventional fan spray nozzle.

Seymour and Byrd (1964) proposed a method of producing uniform spray droplets by mixing a particulating material with the spray liquid (water). This material consists of a fine powder of uniform grain size of a hydrophyllic long-chain polymer. When mixed with water, this material absorbed water, producing small jelly-like, discrete particles. It was hypothesized that this jelly-like material, when forced through a conventional hydraulic nozzle, would break up into particles associated with the original dry polymer particles. If the polymer particles were approximately uniform in size when dry, the resulting jelly particles would also be approximately uniform in size, and if the correct amount of water were added, no free water between the particles would remain, so that no fine, secondary particles would be formed.

Roth (1966) proposed the use of Rayleigh break-up from small jets of liquid issuing from hypodermic tubing to obtain uniform droplets. Rayleigh break-up of liquids with moderate viscosity has satellite droplets associated with the major droplet formation. It was assumed that this spraying device did not produce completely uniform spray, since a certain fraction would consist of satellite drops. The uniformity of spray from such a device might still be better than from conventional hydraulic nozzles.

Walton and Prewett (1949) measured drop size distribution from spinning disc atomizers. Their results showed that the spinning disc atomizer was capable of producing relatively uniform droplets at low flow rates. There was evidence that some satellite droplets were produced. Burt et al. (1966) applied the spinning disc atomizer principle to agricultural work. They introduced an inwardly radial air flow over the periphery of the disc to remove fine satellite drops. Thus only the principal droplet size left the spray device. Their particle size measurements indicate that a coefficient of variation of approximately 0.1 was obtainable by this method.

Sweet (1964) showed that a simple jet issuing from an orifice which was vibrating axially at approximately the same frequency as the Rayleigh break-up frequency on the emerging jet would produce a uniform droplet spray with no satellite drops. The device used for this work included use of a magnetostrictive transducer to drive a single orifice in a small metal block. This is too complicated and has insufficient capacity for a practical spraying device. If an inexpensive method were available for producing a multiplicity of such orifices, and a simpler method were used to drive the nozzles, it might be a practical spraying device.

Schmidt (1967) proposed that uniform spray could be produced by means of a rapidly spinning porous toroid, through which a liquid would flow which would not wet the porous material. Under such circumstances, he reported that the device produced uniform spray. Even when liquids were used that did wet the porous material, spray was produced that was more uniform than that produced by most hydraulic nozzles.

The interest in producing more uniformly sized spray droplets suggests a need for data on the uniformity of droplet size produced now by common agricultural spray nozzles spraying ordinary Newtonian liquids. If work on uniformity of droplet size becomes extensive, simplified methods of measurement would also be useful.

II. OBJECTIVES

The overall objective of this study was to explore factors affecting the size and uniformity of spray droplets. Specific objectives were as follows:

1. To provide reference measurements on the size dispersion of spray from common agricultural spray nozzles to serve for comparison with performance of spray devices or systems which are claimed to produce more uniform spray.

2. To formulate the effect of fluid properties, spray nozzle parameters, and operating conditions on the mean and standard deviation of drop size in terms of dimensionless variables, and test the adequacy of this formulation with experimental measurements.

3. To formulate a simplified method of measuring size and uniformity of spray droplets, and test the adequacy of this formulation with experimental measurements.

III. LITERATURE REVIEW

A. Characterizing Droplet Size Distribution

The introduction has shown that spray droplets are not uniform in size, but rather have a distribution of sizes. The question now arises as to how to best characterize this distribution. The most fundamental approach would be to hypothesize a mathematical form for the distribution function which would fit the distribution data. Some method could then be developed to estimate the parameters of the distribution function.

A number of distribution functions for spray droplet sizes have been proposed, and discussed in earlier literature. Functions which have been discussed and used most frequently are:

a. Normal.
b. Rosin - Rammler
c. Nukiyama - Tanasawa.
d. Logarithmic - normal.
e. Square root normal.
f. Upper-limit logarithmic normal.

Various authors have used all of these functions for characterizing the distribution of drop sizes from various types of spray equipment. Mugele and Evans (1951) made a comparative examination of many distribution functions which had previously been used or proposed for spray drop size distributions. By comparing the goodness of fit of a number of such functions to experimental data, they concluded that the upper-limit logarithmic normal function best fitted most of the experimental data which they were able to examine. This function was written as:

$$f(D) = \frac{D_m}{\sigma(D_m - D)\sqrt{2\pi}} \exp\left[- \ln\left[\frac{D(D_m - \bar{D})}{\bar{D}(D_m - D)}\right] / 2\sigma^2 \right] \quad (1)$$

where[1] D = droplet diameter, D_m = maximum drop diameter, $\bar{D}$ = mean drop diameter, σ = a central tendency parameter, and $f(D)$ = frequency of drops of diameter D produced or sampled during some time interval. This function seemed not only to fit experimental data well, but also met the objection that the logarithmic normal distribution function results in a small, but finite, probability for drops of an absurdly large size.

Although the literature contains numerous discussions of proposed frequency distribution functions for droplet sizes, practical use of these functions for characterizing drop size distribution has been rather limited. The parameters of these functions have less immediate meaning to the user than other descriptive measures which are independent of the distribution function. Also several of the functions are three parameter functions, requiring trial and error solutions.

In previous work on spray distributions, it has been more common to rely upon various descriptive measures, or statistics, to characterize the size distribution. The simplest descriptive measure of central tendency would be the arithmetic mean:

$$D_n = \frac{\Sigma\, n_i D_i}{\Sigma\, n_i} \quad (2)$$

where n_i is the frequency, and D_i is the mid-point, of the ith class

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[1] Notation is defined when first used and summarized in Chapter VIII.

interval.

In spray research literature, the arithmetic mean is commonly referred to as the number mean, or unweighted mean. Spray research workers have been more often interested in the volume of spray contained in various droplet size classes, rather than the number of droplets in each size class. As a consequence, the most common measure of central tendency of spray drop size distribution is the volume median diameter, more frequently referred to as the mass median diameter. The use of this statistic has arisen primarily because of the ease of its calculation. The proportion of spray volume less than or included in each size class is computed, and then plotted against the upper limits of the size classes. The point at which the graph crosses the 50 percentile line is readily determined, and thus the volume median diameter determined graphically.

Volume mean diameter has also commonly been used as a measure of central tendency. There has existed in the literature, however, for some time, two different definitions of this expression. It is surprising that none of the authoritative works in this field (Herdan, 1960; Ranz, 1955; Marshall, 1954) discuss this discrepancy, or even recognize it. No attempt will be made to resolve the differing definitions, or develop a relationship between them. No simple relationship would likely exist because the definitions result from different concepts of the mean.

The volume mean diameter used most frequently in spray research in chemical and mechanical engineering literature is the result of an analogy with the simple arithmetic mean. It is defined as that diameter of droplet which would result if the spray sample were divided into an equal number of uniformly sized droplets. That is:

$$D_{VME} = \left[\frac{\Sigma\, n_i\, D_i^3}{\Sigma\, n_i} \right]^{1/3} \tag{3}$$

This mean will be referred to as the Mugele-Evans volume mean diameter.

The other volume mean results from finding the mean of the drop size volume distribution curve or histogram. Since the volume in each size class would be:

$$V_i = n_i\, D_i^3 \tag{4}$$

V_i (D) becomes a distribution function itself. The mean of this distribution then results from the expression for the arithmetic mean of a distribution, that is:

$$D_{VH} = \frac{\Sigma\, n_i\, D_i^4}{\Sigma\, n_i\, D_i^3} \tag{5}$$

This volume mean diameter will be referred to as the Herdan volume distribution mean diameter.

Because many drop size distributions are approximately normal with respect to the logarithm of the size, the logarithmic - normal distribution is frequently assumed and thus the logarithmic transformation is used. The mean computed from this transformation is known as the geometric mean. It can also be computed from the number distribution as well as the volume distribution. These statistics are defined, respectively, as:

$$D_{gN} = \exp\left[\frac{\Sigma\ n_i\ (\ln D_i)}{\Sigma\ n_i}\right] \tag{6}$$

and

$$D_{gV} = \exp\left[\frac{\Sigma\ n_i\ D_i^3\ (\ln D_i)}{\Sigma\ n_i\ D_i^3}\right] \tag{7}$$

Another measurement of central tendency commonly used in chemical and mechanical engineering processes is the Sauter mean diameter, which is defined as the diameter of droplet having the same ratio of volume to surface as the spray being measured. If a spray, or any dispersed medium, enters into any processes which involve heat and mass transfer through the surface, such as evaporation and drying, combustion or other chemical reaction, or even extraction processes, the Sauter mean diameter is appropriate for prediction of performance of the system. Mathematically, it is defined as:

$$D_{Saut} = \frac{\Sigma\ n_i\ D_i^3}{\Sigma\ n_i\ D_i^2} \tag{8}$$

Compared to the number of statistics used for representation of central tendency of drop size distribution of sprays, it has been a much less common practice to report measures of dispersion of such distributions. Because the median is frequently computed graphically, the inter-quartile range, the 0.1-0.9 decile range, and similar ranges are dispersion statistics which have most often been reported, since the statistics could readily be obtained from the graphical process of computing the median.

Because the logarithmic normal distribution appears to fit many particulate materials, its application for this purpose has been discussed extensively by Aitchison and Brown (1957) and Herdan (1960). Duffie and Marshall (1953) studied the uniformity of spray drops resulting from the break-up of simple low speed jets, and used the geometric standard deviation to characterize the uniformity of the drops. Nelson and Stevens (1961) measured variability of spray droplet sizes in their experimental work. This variability was expressed in their work as the standard deviation of the square root transformed data.

B. Measurement of Droplet Size

Sampling of spray by collection of dyed spray on paper or card stock dates back at least to the work of Riley (1909). While Riley's work dealt principally with visual appraisal of mass distribution and droplet size, the same method was used for quantitative measurement of droplet size from the size of stains by Dorman (1952). Variations in this technique were later described by Davis and Elliot (1953), and Maksymiuk (1964). Middleton and Lowe (1967) report the use of clay coated thin layer chromatography plates for the same functional purpose. The coated cards are convenient to handle, can be used in the field as well as the laboratory, are relatively stable, and can be used in vertical as well as horizontal positions. When dyed spray drops deposit on such a card, the liquid is absorbed into the card forming a stain. The ratio of the stain diameter to diameter of the drop causing the stain is termed the spread factor, and must be determined for each combination of spray liquid and card stock. This spread factor is often a function of the droplet size itself. Thus, to measure distribution of a wide range of droplet sizes requires determination of the spread factor for the same range of droplet sizes. The card stock material is usually a material used for commercial printing, and obtained from commercial sources. Some nonuniformity of the coating and calendaring of the card stock evidently exists, as an apparently inherent variation exists in the spread factor, even when droplet size is held constant. This variation introduces another source of variation into droplet size measurements, therefore making comparisons between tests less sensitive. The work by Middleton and Lowe using clay coated thin layer chromatography plates as a substitute for coated cards was intended to reduce this variation. Thin layer chromatography plates however, lack much of the convenience of handling which the coated cards have.

Castleman (1932) described the use of in-flight flash photography to study the formation of spray and measurement of droplet sizes. Dombrowski (1956) describes many of the details of this method of studying spray. This method was used by Ingebo (1956) more extensively than by any other worker. This method suffered from several limitations. The number of drops which can be sampled in any photograph is usually rather small if sufficient magnification is used to assure that small droplets are recorded. Large droplets are also less likely to be out of focus than small droplets, for any given depth of field of focus, resulting in a biased sampling in favor of larger droplets. Furthermore, if the droplets are not all traveling the same velocity, as for example, in the case where spray may be accelerating due to aerodynamic drag, a bias is also introduced due to the difference between the distribution over space and the distribution over time. Ranz (1955) discussed this bias briefly, and showed that the distribution over time was related to the distribution over space, as follows:

$$f(D) = v(D)\ f'(D)\ /\ \int_0^\infty v(D)\ f'(D)\ dD$$

where $f'(D)$ = frequency of drops of diameter D sampled over some space while in motion, and $v(D)$ is the velocity of drops of diameter D over the same space. In decelerating air flow where the velocity of particles decrease with size, this bias might tend to compensate for the bias due to differing image sharpness. Ingebo corrected for velocity distribution by use of double flash photography so that the $v(D)$ was known. In-flight photography eliminates the need for spread factor measurements, and can be used in studying transient phenomena as well as studying drop-size in difficult situations, such as the work by Ingebo, where the size of burning droplets was measured.

Doble (1947) described a method of drop size determination which collected droplets in a shallow layer of castor oil above a layer of vaseline. Rupe (1949) modified this by use of a less viscous collecting fluid, naptha, in a flat bottom glass cell which was coated with silicone base material to make it hydrophobic. This method eliminated the need for spread factor if the density of the spray liquid and the collecting liquid were close and rather large populations of droplets were to be sampled in a small area. It had a disadvantage that it was sensitive to contamination by dust and particles from other sources and it was restricted to sampling on a horizontal surface. It can only be used for study of sprays from relatively heavy liquids, since the spray liquid must be heavier than the collection liquid in a cell.

Joyce (1946) showed that freezing spray drops immediately after formation in a cold chamber would permit them to be sized with sieving equipment just as any other dry particulate material. This quickly provided weight distribution measurements. This method has been widely used by European workers studying petroleum fuel atomization. Hasson and Mizrahi (1961) have shown that there are circumstances when the frozen drops may introduce errors into the measurements. They attributed this error to recombination of a certain fraction of spray very close to the nozzle tip, which eliminates some fine spray and produces larger drops. If the drops are frozen before this natural recombination occurs, the measurement which results is not representative of that which occurs under normal circumstances.

C. Factors Affecting Droplet Size

Because the formation and use of liquid spray is involved in a number of industrial and chemical processes, an appreciable body of previous research exists describing various spray phenomena. The mechanism of spray formation and factors affecting the resultant droplet size have received considerable attention. The desire to improve the efficiency of fuel burning devices and internal combustion engines stimulated interest in the atomization of hydrocarbon fuels, first with conventional Otto cycle engines, later in diesel engines and more recently in gas turbines and jet engines

The spray nozzles used for hydrocarbon fuels are not very similar to those which are used for agricultural pesticides today. However, since such an extensive literature exists describing nozzles used for hydrocarbon fuel, a brief and abridged review of previous research may be of interest.

Among the earliest studies was that done by Scheubel (1927), who investigated the atomization occurring in carburetors. Scheubel took high speed photographs of water and alcohol being atomized and made droplet size measurements from these photographs. He then correlated the mean droplet size from these measurements with the surface tension, density, and viscosity of the liquid being atomized, and with the velocity of the air. Later, Ohnesorge (1936) studied the formation of spray from a simple jet. He determined that the breakup of the jet into spray passes successively through three different phases. He determined that the criteria for transition from one phase to the next was a function of a dimensionless term, which he denoted by $Z = \mu/(d\ \rho\ \sigma)^{1/2}$, where μ is the viscosity, σ is the surface tension, ρ is the density, and d is the orifice diameter. Later we will show that this term is a simple product of the more conventional Reynolds number and Weber number.

Longwell (1943) conducted a rather extensive study of drop size distribution from swirl chamber nozzles used for oil burners. The experiment was of a classical design and empirical correlations were obtained between mean drop size, cone angle, pressures over a ten-fold range, orifice diameters over a three-fold range, and viscosities over a ten-fold range.

Turner and Moulton (1953) studied the drop size distribution from two types of hollow cone spray nozzle spraying molten betanapthol and molten benzoic acid. An appreciable range of surface tension and viscosity was thus obtained. Orifice diameters from 0.7 mm to 2.0 mm were used, with pressures from 2.2 to 9.0 kg/cm^2. Drop size statistics presented were the geometric mean and geometric standard deviation. Experimental results were presented in tabular form only, with no attempt to prepare a generalized equation.

Tate and Marshall (1953) studied the spray distribution, drop size distribution and capacity of centrifugal pressure nozzles over a range of pressures, orifice diameters, and spray cone angles. Mean drop size, the drop size uniformity, and the cone angle were correlated empirically with a tangential and axial velocity of the liquid as well as the orifice diameter. No comprehensive equation for prediction of drop size was given. Individual formulas and charts were presented on the effect of tangential velocity, axial velocity, viscosity, and orifice size on the mean droplet diameter. They also made limited observations on the uniformity of the drop size distribution.

Nelson and Stevens (1961) also studied the size distribution droplets from centrifugal nozzles spraying a wide variety of liquids. The drop size was related to the liquid and nozzle diameter parameters by a plot of D/d against R $(W/R)^{0.55}(\tan \beta/2)^{1.2}$, where $W = v^2 d\rho/\sigma$ = Weber number, $R = vd\rho/\mu$ = Reynolds number, and β = spray cone angle. They found that water spray values did not plot with data from other liquids but required a separate relationship. Nelson and Stevens also computed the standard deviation of drop sizes resulting from their experiments. By trial and error plotting of the data they found that the standard deviation of the square root transformed data, s_{sr}, could be related to fluid properties and operating conditions by a plot of the variable $s_{sr} W/d^{1/2}$ against $W\ R^{1/2}$. They also studied the effect of spray angle, θ, and found that it was negligible.

At first glance it would seem that the work on drop size distribution from hollow cone spray nozzles might be used to predict similar relationships for the flat fan spray nozzles more commonly used in agricultural work. A hollow cone nozzle spreads the liquid into a sheet of decreasing thickness in the same manner as the fan on a fan spray nozzle, and this rate of spreading by a fan spray nozzle of angle θ would be equal to a conical spray nozzle of angle β by the relationship $\theta = 2\ \pi\beta$. However, while the flow exterior to the nozzle has some similarity, as has just been mentioned, the flow inside the nozzle is considerably different, with the result that even simple phenomena, such as discharge, cannot be predicted with similar equations for hollow cone nozzles and fan spray nozzles. This is due in large part to the presence of the air core in the hollow cone nozzle, and the tangential entrance of the liquid into the nozzle. It has been shown that all liquid leaving hollow cone nozzles must flow through a boundary layer which extends from the back of the nozzle to the orifice. As a result, there is an appreciable range in which an increase in viscosity causes an increase in the discharge coefficient of a hollow cone nozzle, because of the thickening of the boundary layer and consequent decrease in the size of the air core.

Less work has been done on the flat fan nozzle used in agriculture. Dorman (1952) measured the drop size produced by flat fan nozzles over a range of orifice diameters and pressures using kerosene and water. He estimated mean drop size by measuring the size of the largest drop and assuming a constant ratio between the maximum drop size and a mean drop size. He related mean drop size to operating conditions in fluid properties by means of a simplified dimensional analysis which yielded the relationship

$$D_{saut} = 4.4\ (Q/\theta)^{1/3}\ \sigma^{1/3}\ p^{1/6}\ \rho^{1/2} \tag{10}$$

in consistent units, where the coefficient 4.4 was obtained experimentally.

Fraser and Eisenklam (1956) published a survey of much previous research on liquid atomization. In this publication they also included previous unpublished data and empirical correlations on the relationship of droplet size to fluid properties and operating conditions. Two expressions were presented which were claimed to have good agreement with experimental data. These were:

$$D_{saut} = 160\ (\sigma/p)^{0.25}(F/\theta)^{0.37}\rho^{0.065}\ K_Q^{\ 0.98}$$

and

$$\log_{10} D_{saut} = 1.823 + (4.42/p) + 0.0203\ F$$

where F = the flow number (imperial gallons per hour divided by the square root of pressure, lb/in.^{2}), K_Q = the discharge coefficient of the nozzle, σ = surface tension, dynes/cm, Θ = spray angle in radians, p = pressure, lb/in.^{2}, and ρ = liquid density, gm/cm^3.

Fraser et al. (1957) measured drop size of hydrocarbon fuel spray produced by flat fan nozzles. From these data Fraser et al. proposed an empirical equation for predicting the Sauter mean diameter:

$$D_{saut} = 181\ (F\ \sigma/\Theta p)^{1/3} \tag{11}$$

Meyer (1965) measured the droplet size distribution from large flat fan spray nozzles, having equivalent orifice diameters of about 5 to 6 mm, operating at 0.3 to 0.4 kg/cm^2 pressure. No functional relationship between droplet size and operating conditions was attempted, but the results of measurements were tabulated.

Hedden (1961) conducted a series of measurements of drop size from a flat fan spray nozzle at pressures ranging from 1.4 to 18 kg/cm^2. For a particular spray nozzle he found a good fit of experimental data with the following relationship:

$$D_{MM} = a - b \log p$$

where D_{MM} = mass median diameter and a and b are empirical constants. Hedden did not present the statistics on the uniformity of this spray but did present tabular illustrations of the range of droplet sizes produced by spray nozzles, and emphasized the great difference between the arithmetic mean and the mass median diameter for the samples which he took.

Tate and Janssen (1966) measured the drop size distribution from a number of types of agricultural spray nozzles, including the flat fan spray type. The mass median diameter of the spray was tabulated for spray nozzles of different capacities operating at differing pressures, predominantly at 2.8 kg/cm^2. No generalized prediction for drop size was attempted, although the results of the tests were compared with Hedden's data and Fraser's equation. No data on the uniformity of the droplet size were presented.

IV. EXPERIMENTAL PROCEDURE

The previous research studies on drop size distribution from flat fan spray nozzles have one or more of the following shortcomings:

1. The work was conducted with oil base materials. Because Nelson and Stevens (1961) showed that water appeared to perform differently than sprays from all other liquids, it may be unsafe to extrapolate data collected from oil base materials to water sprays, which are predominantly used in agriculture.
2. The relationship between drop size distribution and liquid properties and operating conditions was not formulated in dimensionless terms.
3. Data on the uniformity of the drop size distribution are not presented.
4. Experiments were not conducted over a wide range of operating conditions, e.g., nozzle size and liquid pressure.

The general plan for the experimental work to be conducted in this study, then, was to conduct experiments and collect data in such a way that the deficiencies of previous research were avoided. That is:

1. A wide range, ten-fold or greater, of operating conditions would be covered, including pressure, nozzle capacity, and fan spray angle.
2. A description of the results would be formulated in dimensionless terms, to permit maximum generalization from the data.
3. The experiments would be conducted with water and water base materials.

4. Sufficient data would be collected that the variability of the drop size distribution could be measured, and statistics on dispersion could be computed.

To conduct such experiments, a series of liquids, consisting of various mixtures of water and glycerol, were sprayed from a number of specimens of flat fan spray nozzles obtained from commercial manufacturers. The spray produced was sampled in such a way that counting and sizing of the droplets could be performed on automatic sizing and counting equipment. A wide variety of statistics were computed from these data and compared for their value in characterizing the drop size distribution.

A. Dimensional Analysis

The previous studies by Dorman (1952) and Fraser and Eisenklam (1956) with flat fan nozzles indicated that the surface tension was the fluid property which most strongly affected the spray formation process, and consequently, the resulting droplet size. Both studies, however, also indicated that the density of the spray fluid may have some effect. Neither of these studies seem to indicate the viscosity of the fluid affected the mean droplet size, at least over the range of viscosities which were studied. However, in work with centrifugal nozzles, Nelson and Stevens (1961) found the fluid viscosity affected the mean drop size. Furthermore, much recent agricultural work, such as that by Kirch et al. (1958) has implied that greater uniformity of spray droplet size should be achieved by increasing the viscosity of the spray fluid used. Consequently, it seems reasonable to include the fluid viscosity as a variable which may affect drop size distribution in some manner.

The only operating condition for a flat fan spray nozzle which one can readily change is the pressure. Although Dorman (1952) used the discharge rate of the nozzle as the operating variable, he also included the pressure. Because the discharge rate is affected by both the orifice area and the pressure, this does not logically seem to be an independent variable. In this work we will consider the pressure as the principal operating variable.

The capacity of spray nozzles is varied by changing the orifice area. As a first approximation, at least, if fluid properties and pressures are equal, orifices of equal cross-sectional area will have equal discharge.

To form a flat fan spray, such nozzles often use a conical converging fluid flow, emerging into the surrounding atmosphere through a more or less elliptically shaped orifice. The exact manner in which this orifice is generated to provide a desired angle of spray while maintaining uniformity of flow across the fan is a proprietary art. Approximately, the orifice is generated by the intersection of a simple wedge with a right cone. The boundary of the resulting orifice is described by two inclined elliptical arcs. Proprietary art is involved in modification of the wedge to have a somewhat hyperbolic section and/or modifications of the cone to resemble a paraboloid of revolution or hyperboloid of revolution. Figure 1 shows specimens of such nozzles.

It can be seen from Figure 2 that a series of orifices of differing size can be generated by the intersection of the cone and wedge, depending upon the depth of intersection. However, for orifices of equal area,

Figure 1. Specimens of typical commercial flat fan nozzles, manufactured by Delavan Manufacturing Co., West Des Moines, Iowa (left), and Spraying Systems Co., Bellwood, Illinois (right)

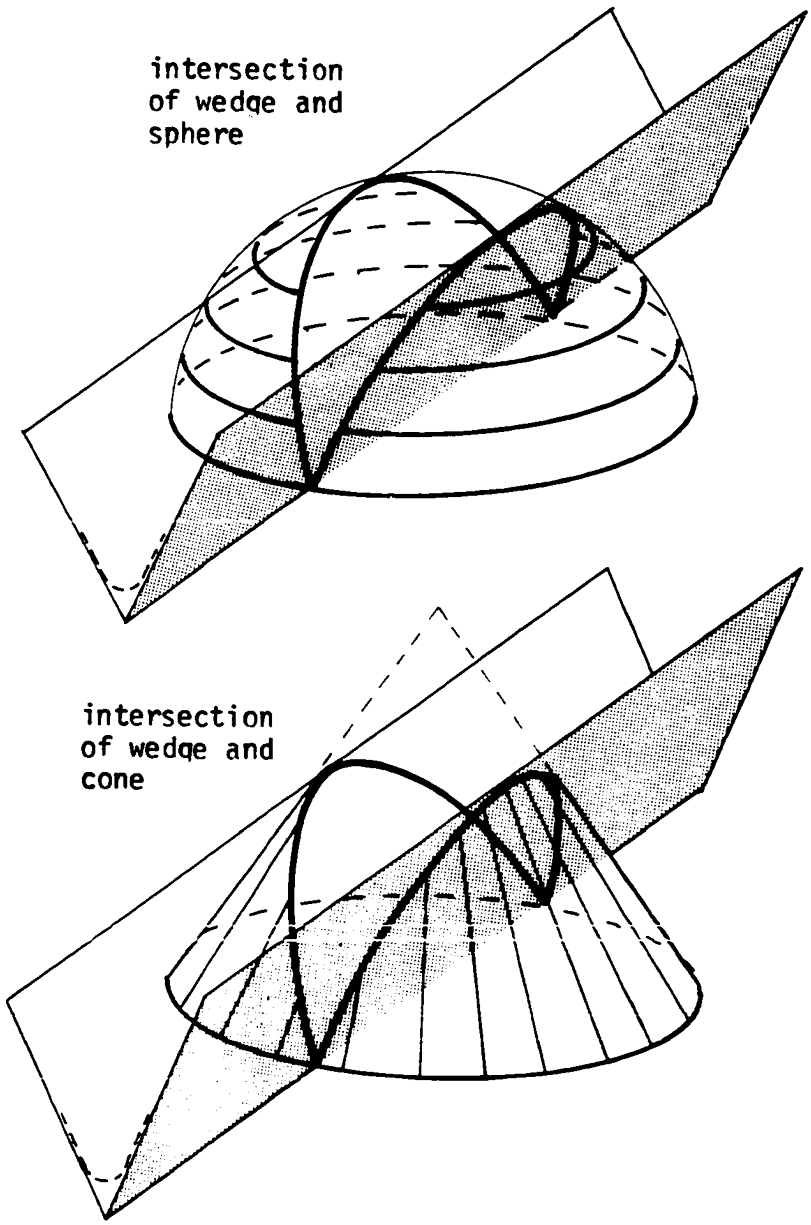

Figure 2. Typical generation of orifice for fan spray nozzle

spray of different fan angle may be generated by varying both the wedge angle and the cone angle. Both the wedge angle and cone angle, as well as departures from the wedge and cone shape, are part of the proprietary art. For the purpose of this investigation it was decided to use nominal spray angle as the spray nozzle variable which described the divergence of flow of the spray nozzle, combining the effect of the more basic nozzle parameters of generating wedge angle and cone angle. The nominal spray angle is defined as the angle of spray produced by a spray nozzle at 40 pounds per square inch. The actual spray angle may vary with the pressure, so is not actually a nozzle design parameter.

Consequently, in this study we will assume that the design of a flat fan spray nozzle is adequately represented by two parameters, the projected area of the orifice, and the nominal spray angle.

At any particular operating condition, a spray nozzle will produce a certain continuous distribution of droplet sizes. In this study, we will characterize this distribution by two statistics; that is, we will characterize the distribution by a statistic measuring central tendency, a mean, and a statistic measuring dispersion, a standard deviation. Many forms of these statistics have appeared in prior literature. Our examination of this literature has not led us to any overwhelming evidence that one form is superior to the others which have also been used. Therefore, in this study the arithmetic mean, D_n, the volume mean diameter, D_{VME}, the volume distribution mean diameter, D_{VH}, the geometric mean of the number distribution, D_{gN}, and the geometric mean of the volume distribution, D_{gV}, will all be computed from the data.

Although it will not be used in the formulation of hypothesis, the Sauter mean diameter will also be computed for all distributions measured so that the data can be compared with the results of other workers who have used it.

As a measure of dispersion, the standard deviation of the droplet distribution will be computed:

$$s_N = \left[\frac{\Sigma\ n_i\ (D_i - D_N)^2}{\Sigma\ n_i}\right]^{1/2} \qquad (12)$$

The standard deviation of the volume distribution will also be computed, defined as:

$$s_{VH} = \left[\frac{\Sigma\ n_i D_i^3 (D_i - D_{VH})^2}{\Sigma\ n_i D_i^3}\right]^{1/2} \qquad (13)$$

The geometric standard deviation will also be computed, defined as:

$$s_{gN} = \left[\frac{\Sigma\ n_i (\ln D_i - \ln D_{gN})^2}{\Sigma\ n_i}\right]^{1/2} \qquad (14)$$

The geometric standard deviation of the volume distribution will be computed, defined as:

$$s_{gV} = \left[\frac{\Sigma\ n_i D_i^3 (\ln D_i - \ln D_{gV})^2}{\Sigma\ n_i D_i^3}\right]^{1/2} \qquad (15)$$

The common fitting of the logarithmic normal distribution to spray data implies that the dispersion of the drop size distribution may be proportional to the mean of the distribution. In order to compare the relative uniformity of coarse and fine sprays, the coefficient of variation will be computed as the measure of the relative uniformity of all sprays. This will be done for both the number distribution and the volume distribution of the spray. The coefficient of variation is a dimensionless variable. The geometric standard deviations are also dimensionless variables, and have been shown by Aitchison and Brown (1957) to be related to the coefficient of variation.

The previous literature and the above discussion lead to the following hypothesis:

HYPOTHESIS: If the resulting drop diameter distribution from a flat fan spray nozzle is characterized by a mean diameter, $\overline{D}$, which may stand for D_n, D_{VH}, D_{VME}, D_{gN}, or D_{gV}, and a coefficient of variation, c, which may stand for s_n/D_N, s_{VH}/D_{VH}, s_{gN}, or s_{gV}, then

$$\overline{D} = F(p, \rho, \sigma, \mu, A, \theta) \tag{16}$$

and

$$c = G(p, \rho, \sigma, \mu, A, \theta) \tag{17}$$

These relationships can be formulated in dimensionless terms by accepted procedures. Generally, this would yield

$$\Pi_1 = f(\Pi_2, \Pi_3, \Pi_4) \tag{18}$$

$$\Pi_1' = g(\Pi_2, \Pi_3, \Pi_4) \tag{19}$$

where $\Pi_1 = \bar{D}/A^{1/2}$, $\Pi_1' = c$, $\Pi_2 = A^{1/2}p/\sigma$, $\Pi_3 = A^{1/2}p^{1/2}\rho^{1/2}/\mu$, and $\Pi_4 = \theta$. Substitution of these terms would yield

$$\frac{\bar{D}}{A^{1/2}} = f\left(\frac{A^{1/2}p}{\sigma}, \frac{A^{1/2}p^{1/2}\rho^{1/2}}{\mu}, \theta\right) \tag{18a}$$

$$c = g\left(\frac{A^{1/2}p}{\sigma}, \frac{A^{1/2}p^{1/2}\rho^{1/2}}{\mu}, \theta\right) \tag{19a}$$

Relationships of other dimensionless terms might be used instead. Any such dimensionless terms would be, in turn, products of the terms listed above. Our choice of the products used is justified only by the long usage and the prior literature on fluid mechanics, the expression $A^{1/2}p/\sigma$ being related to the Weber number, and the expression $A^{1/2}p^{1/2}\rho^{1/2}/\mu$ being related to the Reynolds number.

The work of many previous workers can be cast in the form shown above by appropriate algebraic manipulation in order to compare data. For example, Dorman (1952) showed that his data yielded:

$$D_{saut} = 4.4(Q/\theta)^{1/3} \ \sigma^{1/3} \ p^{1/6} \ \rho^{-1/2}$$

For flow through a nozzle we know that

$$Q = K_f A \ (2p/\rho)^{1/2}$$

Where K_f is the flow coefficient for the nozzle under the given operating conditions. Thus, rewriting

$$D_{saut} = 4.4 \left[Q^2 \ \theta^{-2} \ \sigma^2 \ p \ \rho^{-3}\right]^{1/6}$$

substituting

$$D_{saut} = 4.4\ K_f^{1/3}\ 2^{1/6} \left[A^2\ \theta^{-2}\ \sigma^2\ \rho^{-2}\right]^{1/6}$$

dividing by $A^{1/2}$

$$\frac{D_{saut}}{A^{1/2}} = 4.95\ K_f^{1/3} \left(\frac{A^{1/2}\ \rho}{\sigma}\right)^{-1/3} \theta^{-1/3} \tag{20}$$

which is a functional relationship of the form derived by dimensional analysis above.

No such manipulation would be possible on either of the equations presented by Fraser and Eisenklam (1956), as they are both dimensionally inconsistent. Similar arrangement of the equation from Fraser et al. (1957) (Equation 11) yields

$$\frac{D_{saut}}{A^{1/2}} = 2.5\ K_f^{1/3} \left(\frac{A^{1/2}\ \rho}{\sigma}\right)^{-1/3} \theta^{-1/3} \tag{21}$$

No explanation can be given for the obvious discrepancy between this and the result from rearrangement of Dorman's equation (Equation 20).

B. Experimental Design

Where several independent dimensionless terms exist and the experiments are done in the classical way, with tests performed at several levels of each dimensioned variable, the results usually do not yield values of dimensionless variables at distinct levels. Consequently, it is difficult to fit any type of prediction equation to the results other than a simple straight line regression equation.

Experiments could be designed in the space defined by the independent dimensionless variables, and derive from this design the values required for dimensioned variables to satisfy the experimental design. Such an approach was used in this study.

It was recognized that the hypothesis constitutes a response surface of the dependent dimensionless term $\Pi_1 = \bar{D}/A^{1/2}$ as a function of the independent dimensionless terms $\Pi_2 = P\ A^{1/2}/\sigma$, $\Pi_3 = p^{1/2}\ \rho^{1/2}\ A^{1/2}/\mu$, and $\Pi_4 = \theta$.

To enable us more carefully to fit a functional relationship to the experimental data to be obtained, it would be convenient if experiments were conducted in such a way that the resulting independent dimensionless variables formed an orthogonal array, preferably incremented in some consistent fashion, as illustrated in Figure 3.

The first step was to explore how a plane defined by the variables p and A, when σ, μ, and ρ were held constant by using a single liquid, mapped onto the plane defined by Π_2 and Π_3. Figure 4 shows the locus experimental conditions of a series of tests conducted with a nozzle of fixed orifice but varying pressure. Figure 5 shows the locus of points described with a constant pressure but varying orifice size. Figure 6 shows the result of a classical experiment where both orifice size and pressure were varied systematically using a single fluid.

Several things become evident from inspection of this mapping. First, a considerable area of the plane can be covered with a single fluid by varying the nozzle size and pressure. It is still limited, however, as the range of practical pressure is restricted from approximately 0.5 kg/ cm^2 to about 15 kg/cm^2 and the range of practical nozzle sizes is 0.1 mm^2 to about 1 mm^2.

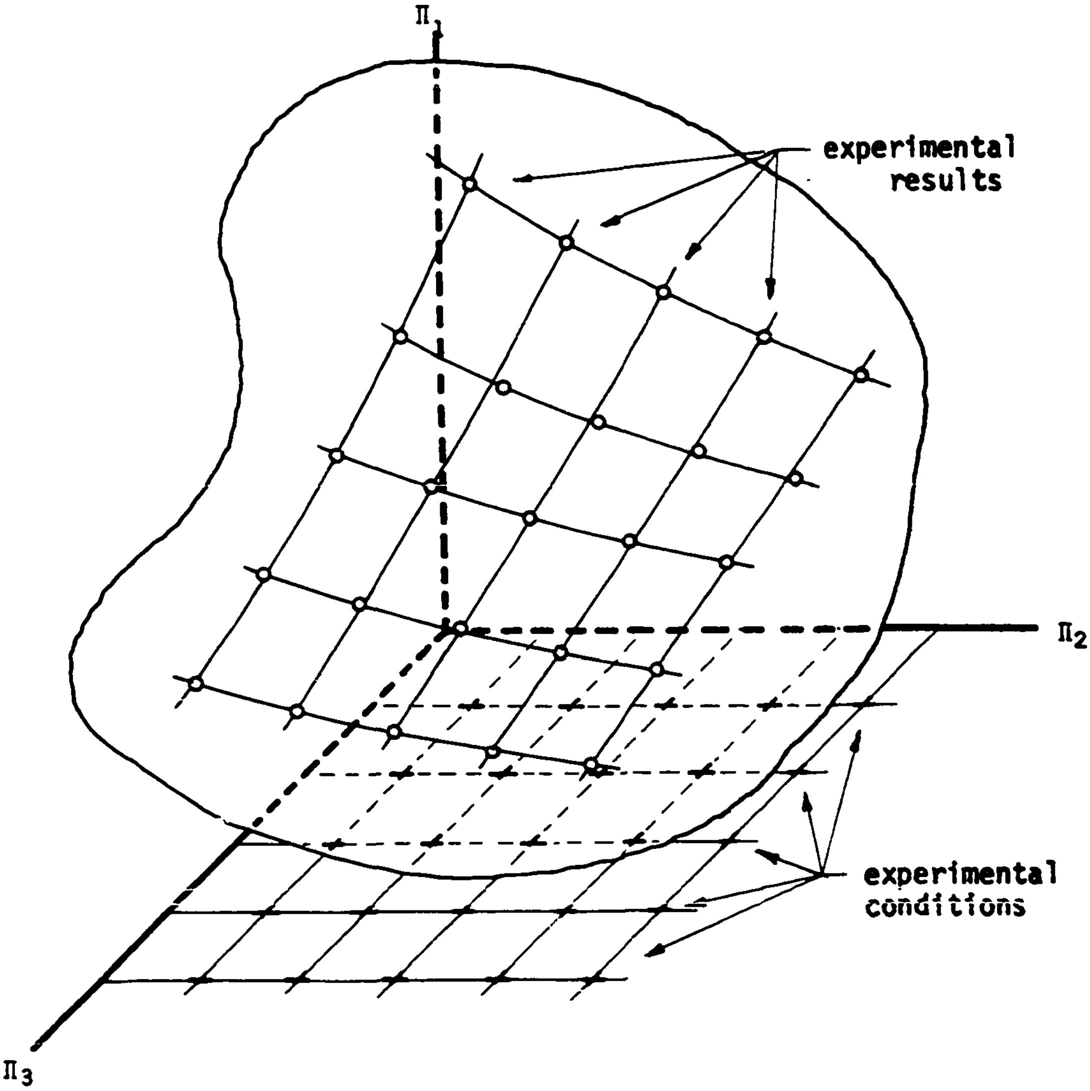

Figure 3. Diagram of ideal response surface and orthogonal array of experimental conditions for dimensionless variables

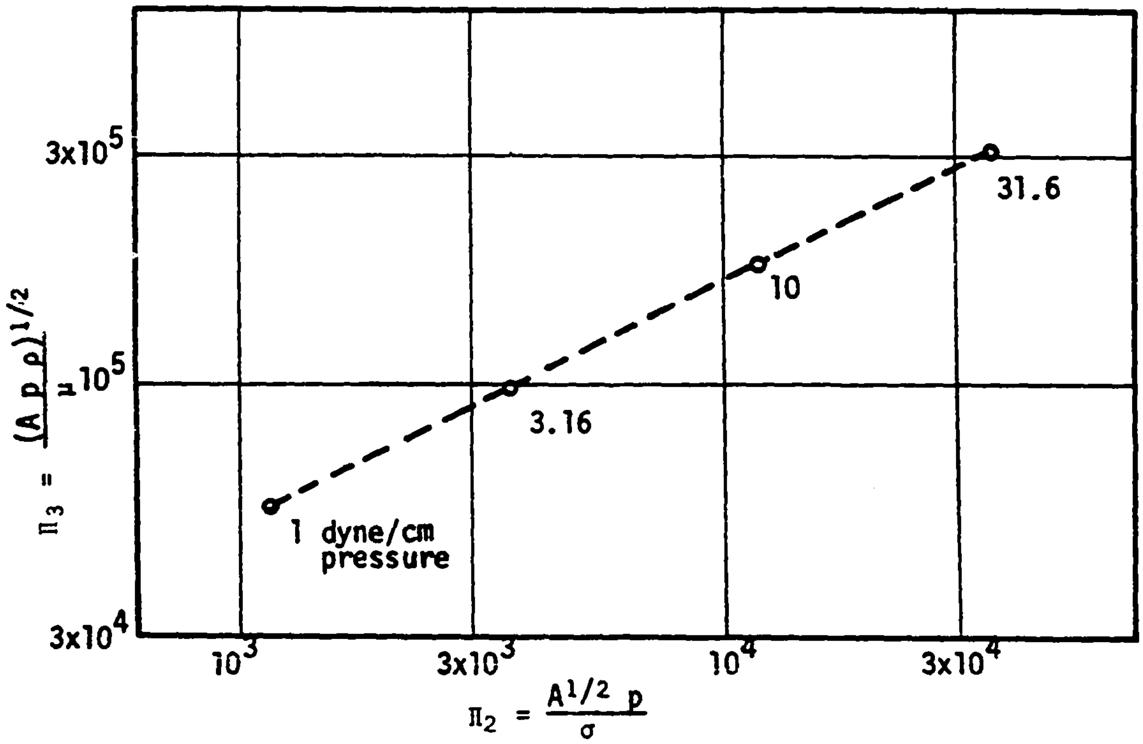

Figure 4. Locus of tests with single liquid and orifice size

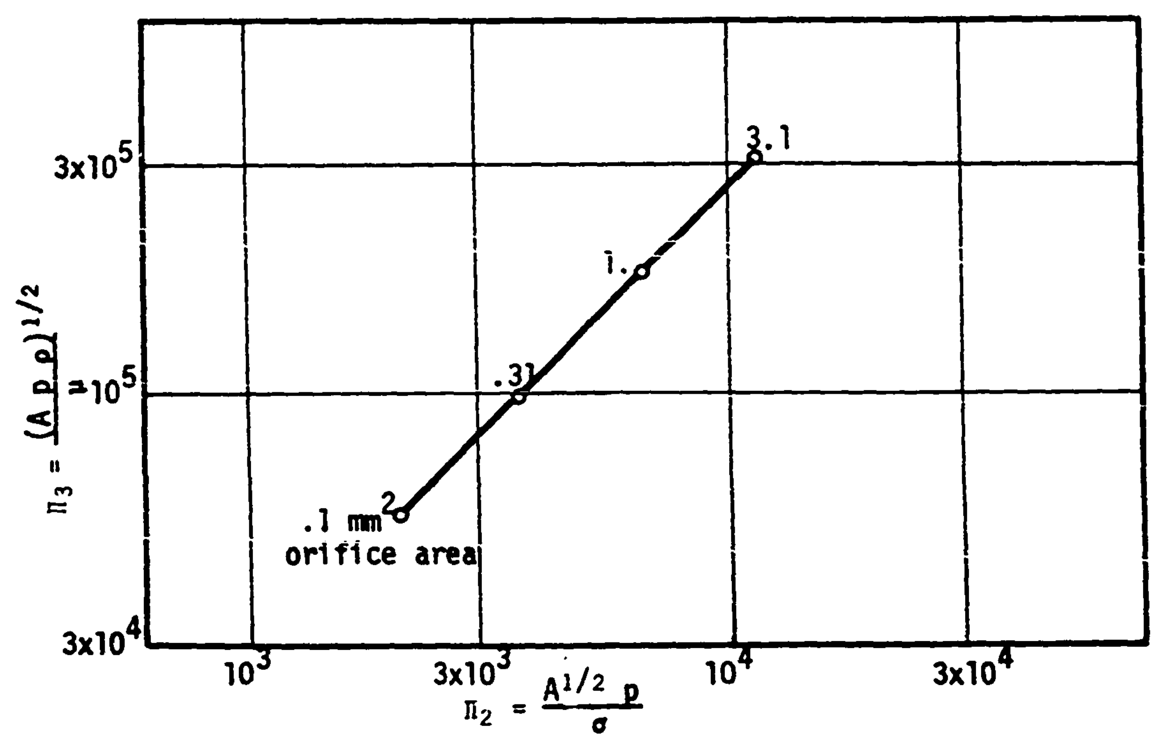

Figure 5. Locus of tests with single liquid and constant pressure

Secondly, even in this relatively simple experiment some orthogonal comparisons exist. That is, a curve in Figure 6 through F-G compares varying Π_3 at constant Π_2. So does a curve through C-D or I-J. Similarly, a curve through C-E-G or F-H-J compares the effect of varying Π_2 at constant Π_3.

Furthermore, if a liquid were available having the same surface tension but 1.78 greater viscosity, the immediately adjoining area in the Π_2-Π_3 plane could be covered by a similar series of experiments, as shown in Figure 7. The restriction of equal surface tension is not strictly necessary. By adjusting the sizes of nozzles and operating pressures, a series of experiments could be performed extending over a wider range of Π_3 while still maintaining constant Π_2 and also extending over a wider range of Π_2 at constant Π_3. If it were possible to conduct the same series of tests with additional liquids having progressively greater viscosity, correct choice of pressure and nozzle size could result in a considerable extension of tests at either constant Π_2 or constant Π_3.

Such experiments could be conducted most conveniently with mixtures of two liquids having surface tension and density values which are not greatly different. Water and glycerol have such properties, and as a consequence, mixtures of these liquids can be prepared which have widely varying viscosity with relatively little variation in density and surface tension. Since water exhibits a relatively small change of surface tension and density with changes of temperature, while the viscosity changes considerably, tests could be extended to higher values of Π_3 by conducting tests with heated water.

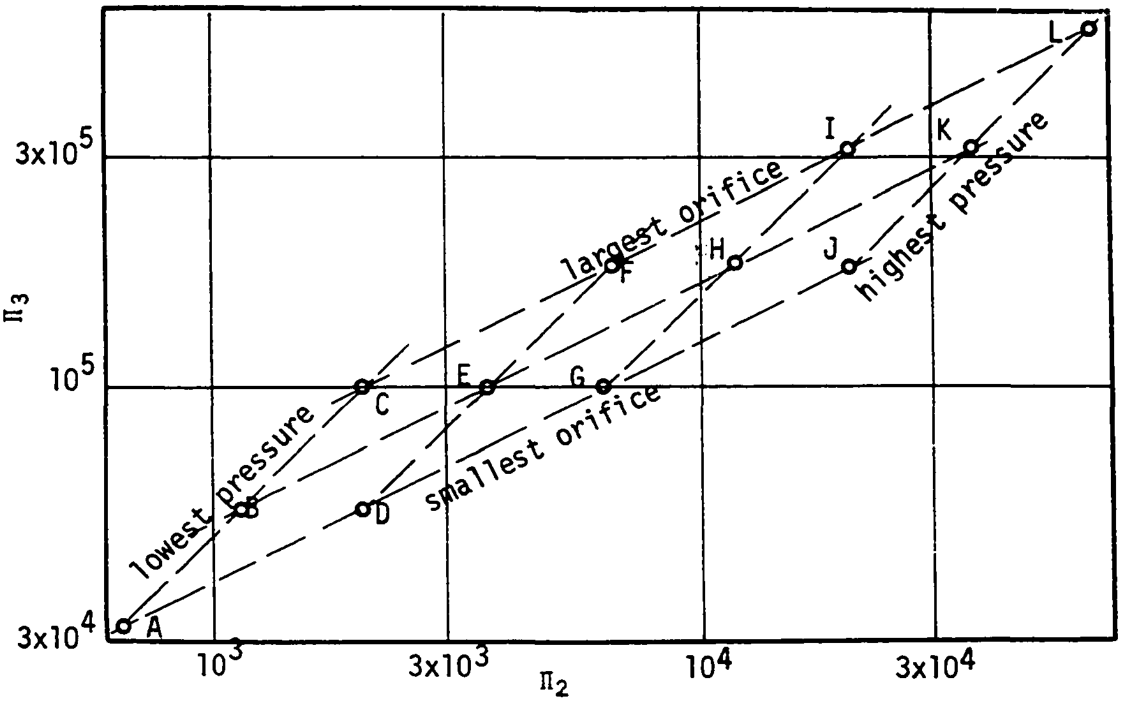

Figure 6. Locus of dimensionless independent variables in a classical experiment

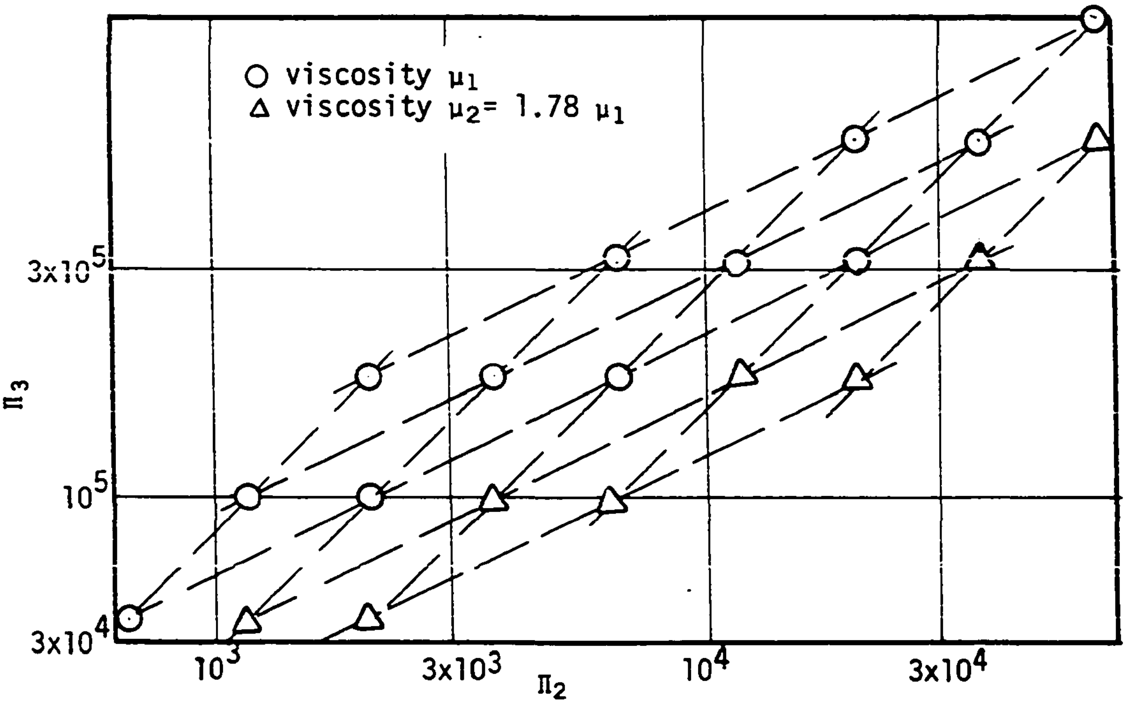

Figure 7. Result of repeating experiment with liquid having greater viscosity and equal surface tension

Based upon this general line of reasoning, the following basic experimental design was developed. Specimens of commercial flat fan spray nozzles were flow rated and specimens selectively chosen such that specimens were available which had orifice areas in the ratios $1, \sqrt{10}$, and 10. These nozzles were operated with water heated to two different temperatures, plus various mixtures of water and glycerol at 20°C such that viscosities of the liquids used were logarithmically equal spaced in ratios of 1.78 which requires four different fluids to cover a ten-fold range of viscosities. The experiments are shown on the Π_2-Π_3 plane on Figure 8. The points at tests number 9, 16, 40, 47, 54, and 15 encompass the conditions under which the bulk of agricultural spray operations is now conducted. To gain a better understanding of the effect of surface tension and viscosity, tests were extended in a more or less orthogonal fashion, but over wider increments of Π_2 and Π_3, to the area encompassed by experiments number 3, 2, 1, 51, 34, 48, 65, 66, 64, 49, 61, 33, 14 and 68.

To compare the results of experiments with different liquids conducted at identical conditions of Π_2 and Π_3, experiments 15, 16, 19, were performed for comparison with tests number 30, 21, and 20, as shown in Figure 9.

To obtain an estimate of the variance in measurements of drop size distribution, experiments 17 and 18 were performed as replicates of experiment 16 and experiments 22 and 23 were performed as replicates of experiment 21.

All of the tests described above in the basic experimental design

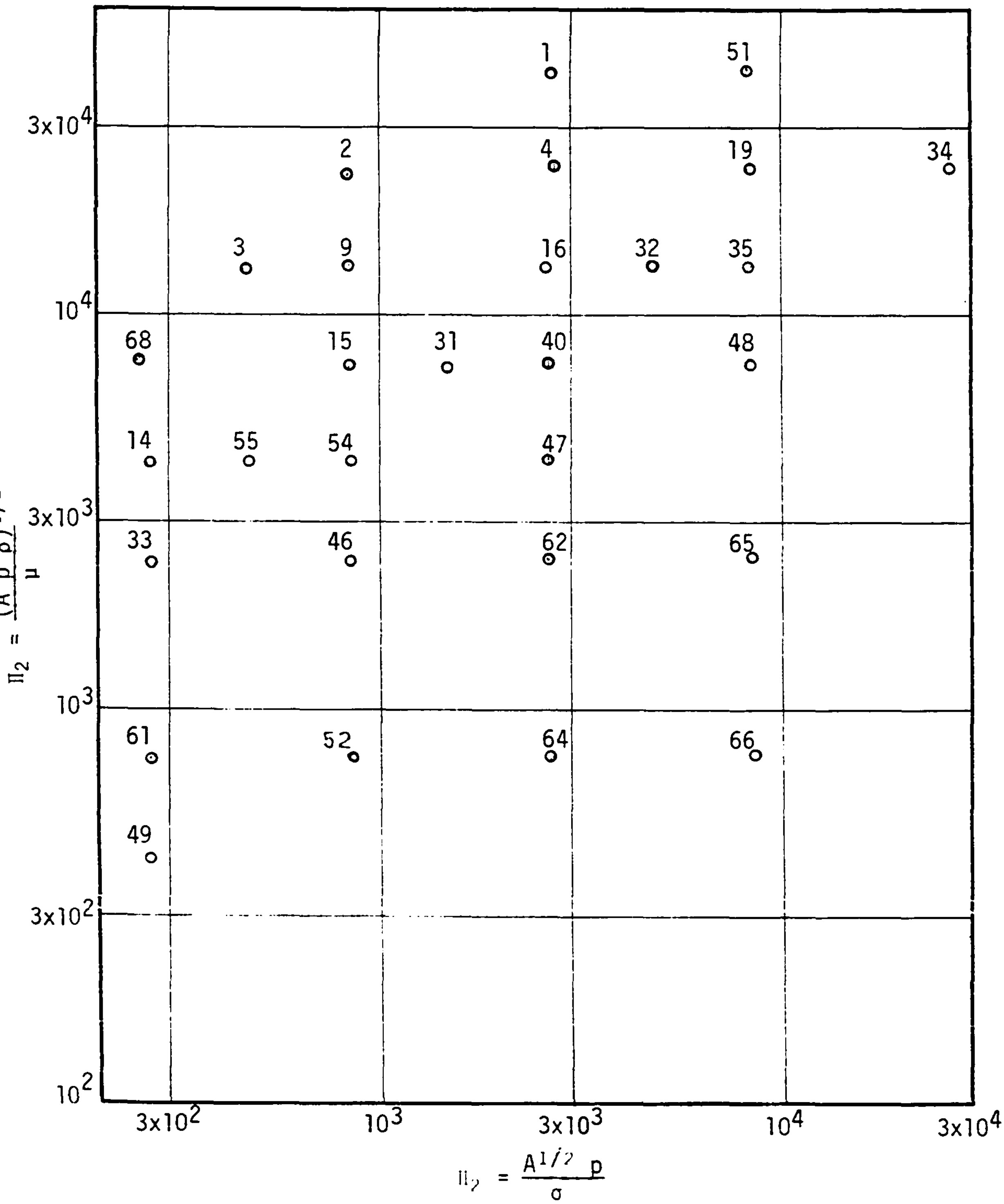

Figure 8. Locus of dimensionless independent variables in basic experimental design

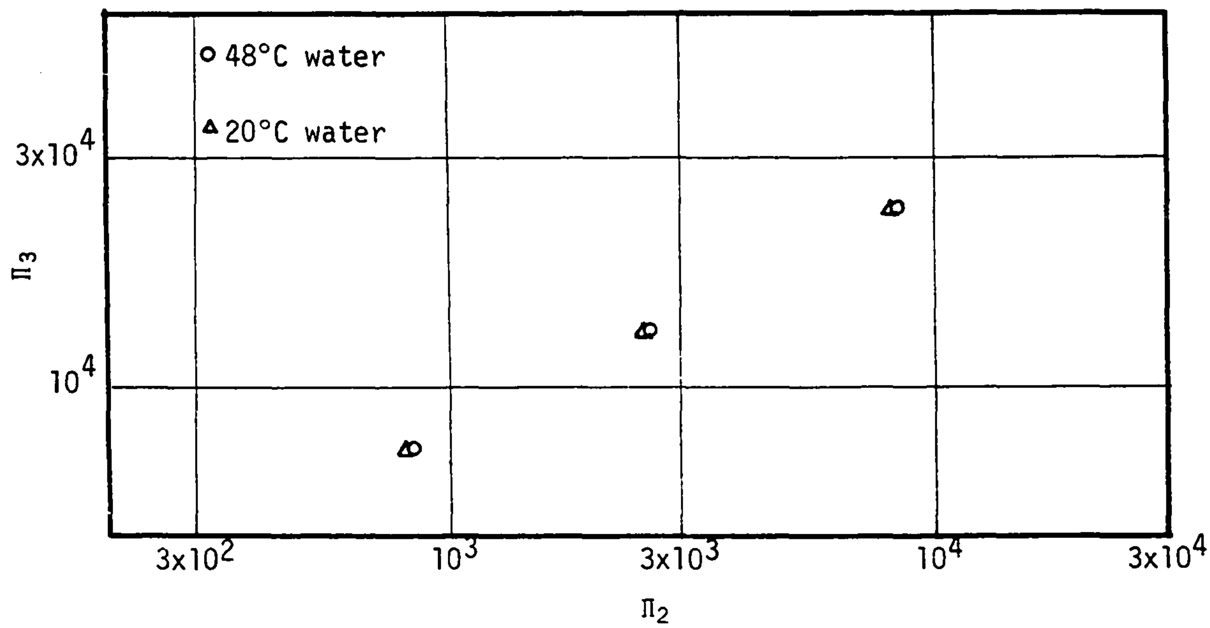

Figure 9. Tests conducted having identical condition of dimensionless independent variables but using liquids with different properties

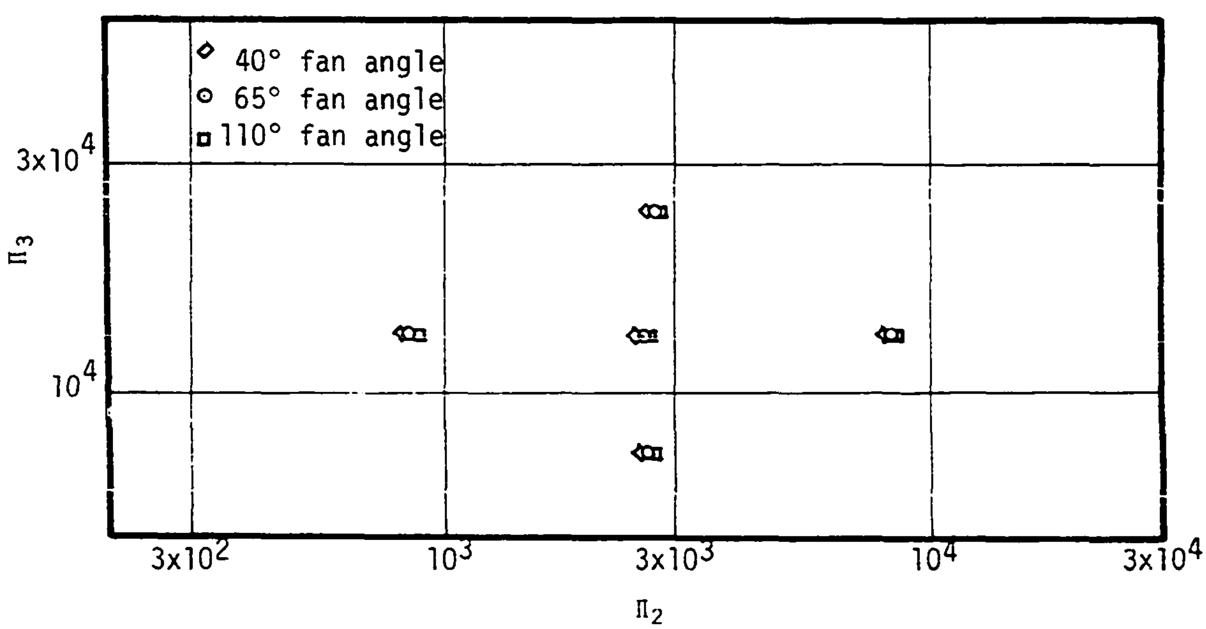

Figure 10. Locus of tests conducted with different nominal spray angle nozzles

were conducted with nozzles having a spray angle of approximately 65°. In order to test the effect of spray angle, the additional series of tests number 9, 11, 4, 6, 27, 28, 57, 58, 59, and 60 were conducted with nozzles having a nominal angle of 40° and 80°. Additional tests number 26 and 29 were conducted with nozzles having nominal spray angles of 15° and 110°. These test conditions are shown on a Π_2-Π_3 plot in Figure 10.

The conditions describing all planned experiments are shown in Table 1.

Table 1. Summary of planned experiments

Test number	Liquid used	Viscosity poise	Surface tension dyne/cm	Nozzle used	Pressure used lb/in.^{2}
1	90°C water	0.0031	60	6503A	28.5
2	"	"	"	"	9.0
3	"	"	"	6501	"
4	48°C water	0.0056	68	6503A	28.5
5	"	"	"	4003	"
6	"	"	"	11003	"
9	"	"	"	6503A	9.0
10	"	"	"	4003	"
11	"	"	"	11003	"
14	"	"	"	650033C	"
15	"	"	"	650033C	28.5
16	"	"	"	650033A	90.0
17	"	"	"	650033B	"

Table 1. (Continued)

Test number	Liquid used	Viscosity	Surface tension	Nozzle used	Pressure used
		poise	dyne/cm		lb/in.^{2}
18	48°C water	0.0056	68	650033C	90.0
19	"	"	"	"	285.0
20	20°C water	0.010	72	6503A	90.0
21	"	"	"	"	28.5
22	"	"	"	6503B	"
23	"	"	"	6503C	"
26	"	"	"	1503	"
27	"	"	"	4003	"
28	"	"	"	8003	28.5
29	"	"	"	11003	"
30	"	"	"	6503A	9.0
31	"	"	"	6501	28.5
32	"	"	"	"	90.0
33	"	"	"	650033C	9.0
34	0°C water	0.0178	75	6503A	285.0
35	"	"	"	"	90.0
36	"	"	"	4003	"
37	"	"	"	11003	"
40	"	"	"	6503A	28.5
41	"	"	"	4003	"
42	"	"	"	11003	"
46	"	"	"	650033C	"

Table 1. (Continued)

Test number	Liquid used	Viscosity	Surface tension	Nozzle used	Pressure used
		poise	dyne/cm		lb/in.^{2}
47	0°C water	0.0178	75	650033C	90.0
48	"	"	"	"	285.0
49	55.5% glycerol solution	0.0562	70	"	9.0
50	"	"	"	"	285.0
51	48°C water	0.0056	68	6503A	90.0
53	20°C water	0.010	72	650033C	"
54	"	"	"	"	28.5
55	"	"	"	6501A	9.0
56	23.8% glycerol solution	0.0178	"	6503A	90.0
57	"	"	"	4003	"
58	"	"	"	11003	"
59	"	"	"	4003	28.5
60	"	"	"	11003	"
61	40.0% glycerol solution	0.0316	71	650033C	9.0
62	"	"	"	650033C	90.0
63	"	"	"	6503A	"
64	60.0% glycerol solution	0.100	69	65003	"
65	"	"	"	6503A	"
66	67.7% glycerol solution	0.178	68	650033C	285.0
67	23.8% glycerol solution	0.0178	72	6503A	28.5
68	90°C water	0.0031	60	650033C	9.0

C. Control and Measurement of Variables

The size of nozzle orifices was controlled by measuring the flow rate of a number of commercial spray nozzles at 40 lbs per sq in., the pressure at which manufacturers frequently specify the discharge to be equal to the nominal rating. From the collection of nozzles which were measured in this way, specimens were chosen which showed, as closely as possible, flow rates in the ratio of 1, $\sqrt{10}$, and 10. Three closely matched specimens were chosen of both the largest and the smallest nozzle sizes.

Nominal spray angles were measured by photographing the spray fan when operating at 40 lbs per sq in., and measuring the flow in degrees with a protractor from the photograph. This angle was then converted to radians. Measurement of the spray angle was somewhat subjective, and may have been subject to as much as two degrees of error.

The pressure in the fluid was measured 0.3 cm behind the spray orifice with a commercial bourdon tube pressure gage. The two lower pressures were measured with a 0 - 30 lbs/in.^{2} gage of ± 2 percent accuracy. This gage was checked against a 0 - 60 lb/in.^{2}, ± 1 percent accuracy gage, and found to be accurate within the limits of reading precision at the two pressures used. The two higher pressures were measured on 0 - 150 lb/in.^{2}, 5 percent accuracy, and 0 - 300 lbs/in.^{2}, ± 5 percent accuracy gages. No calibration source was available for these two gages, and they were used uncalibrated.

The viscosities of all liquid spray were measured with Ostwald-Fenske viscometers, a capillary tube type viscometer which measures the time for a metered amount of liquid to flow through a capillary tube under gravity.

The viscometers were purchased uncalibrated and were calibrated using distilled water at 20°C. The glycerine solutions were prepared by estimating the proportion of glycerine required to produce the desired viscosity from tabulated values of viscosity for aqueous glycerol solutions given in Handbook of Chemistry and Physics (1959). Three measurements of the viscosity were then made with the Ostwald-Fenske apparatus, and additional water or glycerol was added to bring the viscosity closer to the value desired. After additional mixing, the viscosity was again measured, and the process repeated until the viscosity measured was within three decimal place accuracy of the value desired. The tests were conducted in air-conditioned rooms maintained at 20°C. The temperature of the spray liquid was also measured immediately before pouring it into the spray tank of the experimental apparatus. The control of the temperature of heated water used in several of the experiments was maintained by heating it to approximately 5°C higher than the temperature desired for the test, pouring the liquid into the spray tank, applying a small amount of pressure, and then closing the outlet valve to fill the piping with hot water. Water was then left in the apparatus to heat the spray tank and piping. The hot water was then run out of the spray tank through the nozzle piping with the nozzle removed, reheated quickly to 5° above the desired temperature again, and poured into the spray tank and the piping line filled as before. After the water had remained in the tank for several minutes it was run out through the nozzle piping with the nozzle removed and the temperature of the liquid measured. This process was repeated until the temperature of the liquid leaving the spray piping was exactly the temperature desired. At that point, the liquid was re-heated to one degree above the desired temperature, poured into the tank, and the experiment run immediately. The spray tank was insulated with two inches of fiberglass batt insulation, and the piping leading to the spray nozzle was insulated with one inch of fiberglass wraps. No temperature control system was used in the spray tank and the piping to the nozzle. Thus the temperature at the nozzle could have varied $\pm 1°C$.

The surface tension of the liquid was measured with a double bubble surface tensiometer calibrated with reagent grade benzene. Accuracy of this equipment is affected somewhat by the care with which the airflow is adjusted. For this reason it may not be as accurate as the ring type method for pure liquids. However, since it measures the surface tension on new rapidly forming surface, it is less affected by surface active agents, and therefore more representative of the surface tension acting during the spray formation process. For this reason, perhaps, the surface tension measurements shown for the spray liquid, which contains a 2 percent solution of nigrosine dye, is higher than reported by other workers using dyed water, as, for example, Rupe (1949). The density of the spray liquid was not measured, as precision equipment for this purpose was not available. Values used were taken from tabulated data in the Handbook of Chemistry and Physics (1959).

To measure the area of nozzle orifices, the orifices were photographed at 2X magnification on fine grain film, and the resulting negatives were enlarged to approximately 20X. The area of the orifice image on the print was then measured with a planimeter, and the exact magnification of the photographic print was measured by comparison with microscopic measurement of the orifice diameter.

D. Collection of Spray Samples

Spray formed by the nozzles was collected using a procedure similar to that described by Rupe (1949). Flat bottom petri dishes were coated on the inner bottom and sides to make the glass surface hydrophobic. This prevents collected spray drops from spreading on the surface. The interior of two dishes was wiped with a small cotton swab wetted with dimethyldichlorosilane, two drops of water were placed in one of the dishes and the other dish placed face to face with it, and taped together with vapor proof plastic adhesive tape. The interiors of the dishes were then exposed by this method, to the vapor of dimethyldichlorosilane and water for approximately 48 hours, after which the tape seal was removed, and the dishes rinsed with water, methanol, and again with water. This is an adaptation of a procedure suggested by Howard and Martin (1950) to confer hydrophobic properties on diatomaceous earth column support materials used for gas chromatography. Glass surfaces treated in this way were found to be more consistently hydrophobic than when treated by other methods which have been proposed, such as with the solutions of silicone resins (Tate and Marshall, 1953). The hydrophobic surface thus formed was stable and not easily damaged, except by high pH detergents.

The dishes were filled to a depth of 3 - 4 mm with Stoddard solvent, a commercial naptha. Five such dishes were placed in a symmetric linear array directly under the spray nozzle and centered in the spray deposit pattern. The 15°, 40°, 65°, and 80° fan angle nozzles were located 50 cm above the dishes. The 110° fan angle nozzle was located 30 cm above the dishes. The dishes were separated from the spray nozzle by a continuous movable rubber membrane containing a 2 cm wide slot perpendicular to the direction of travel of the membrane. Movement of the membrane thus acted as a shutter to permit a portion of the spray to fall into the dishes. The shutter was moved by hand, by pulling it with a small cord. An attempt was made, when operating the shutter, to move it at a speed proportional to the discharge rate of the nozzle. This was approximately 0.5 ft/sec for small nozzles increasing to approximately 2 ft/sec for the large nozzles. This range of speeds, however, was still not sufficient to provide a uniform deposit of spray, as some samples had to be discarded because of too heavy deposits. Figure 11 shows one dish in position under the shutter. The nozzle to be tested is also visible in the photograph.

To insure that the sample of spray was taken from the center of the pattern, prior to each experiment a sheet of white paper was laid over the shutter and the nozzle operated momentarily to observe the location of the pattern over the shutter.

After many experiments had been conducted with this apparatus, it was observed that the small water droplets were shrinking in size rather quickly after their collection in the naptha. Figure 12 shows the size of spray droplets collected in 20°C Stoddard solvent as a function of time elapsed after collection. This phenomena, although discussed by Fraser and Eisenklam (1956), does not appear to have been discussed by other workers who have used the Rupe cell. This decrease in size is attributed to the small, but sufficient, solubility of the water in naptha. Because

Table 2. Nozzles used for experiments

Specimen designation	Working designation[1]	Nominal fan angle degrees	Projected orifice area mm^2	Discharge of water at 40 psi ml/sec
A	650033A	64	0.0914	1.915
B	650033B	66	0.0937	1.963
C	650033C	66	0.0908	1.903
D	6501	64	0.2888	5.992
E	1503	14	0.7673	15.66
F	4003	38	0.8487	17.06
G	6503A	65	0.9293	18.68
H	6503B	67	0.9258	18.61
I	6503C	67	0.9317	18.73
J	8003	81	0.9977	19.92
K	11003	110	0.9301	18.70

[1]Selected specimens of nozzles manufactured by Spraying Systems, Inc., Bellwood, Illinois, during 1964.

Table 3. Liquids used for experiments

Liquid designation	Material used	Viscosity poise	Surface tension dyne/cm	Density gm/cm^3
A	98% water, 2% nigrosine at 90°C	0.0031	60	0.9653
B	98% water, 2% nigrosine at 48°C	0.0056	68	0.9889
C	98% water, 2% nigrosine at 20°C	0.010	72	0.9982
D	98% water, 2% nigrosine at 4°C	0.0178	76	0.9999
E	23.8% glycerol, 74.8% water, 2% nigrosine at 20°C	0.0178	72	1.0566
F	40.0% glycerol, 58.0% water, 2% nigrosine at 20°C	0.0316	71	1.0995
G	55.5% glycerol, 42.5% water, 2% nigrosine at 20°C	0.0562	70	1.1412
H	60.0% glycerol, 38.0% water, 2% nigrosine at 20°C	0.100	69	1.1533
I	67.7% glycerol, 31.3% water, 2% nigrosine at 20°C	0.178	68	1.1715

it was felt that this phenomena would introduce a bias into the measurement technique, a search was made for liquids which have appreciably less solubility for water than naptha. A number of liquids were investigated, including silicone oils, but none were found.

Presaturation of the naptha with water prior to its use in the Rupe cell was found to have no practical effect in reducing the rate of spray

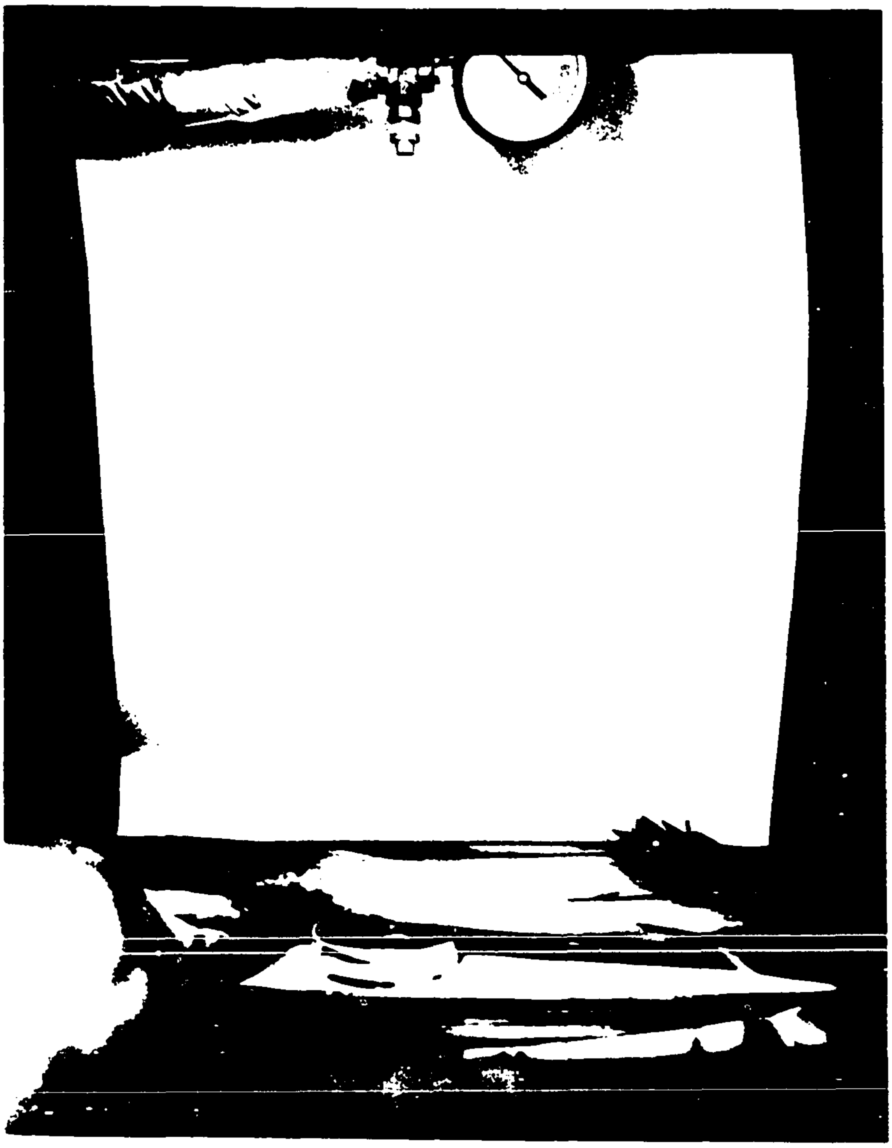

Figure 11. Interior of spray collection chamber. Shroud in front of dishes is pushed up to show position of dishes under the shutter

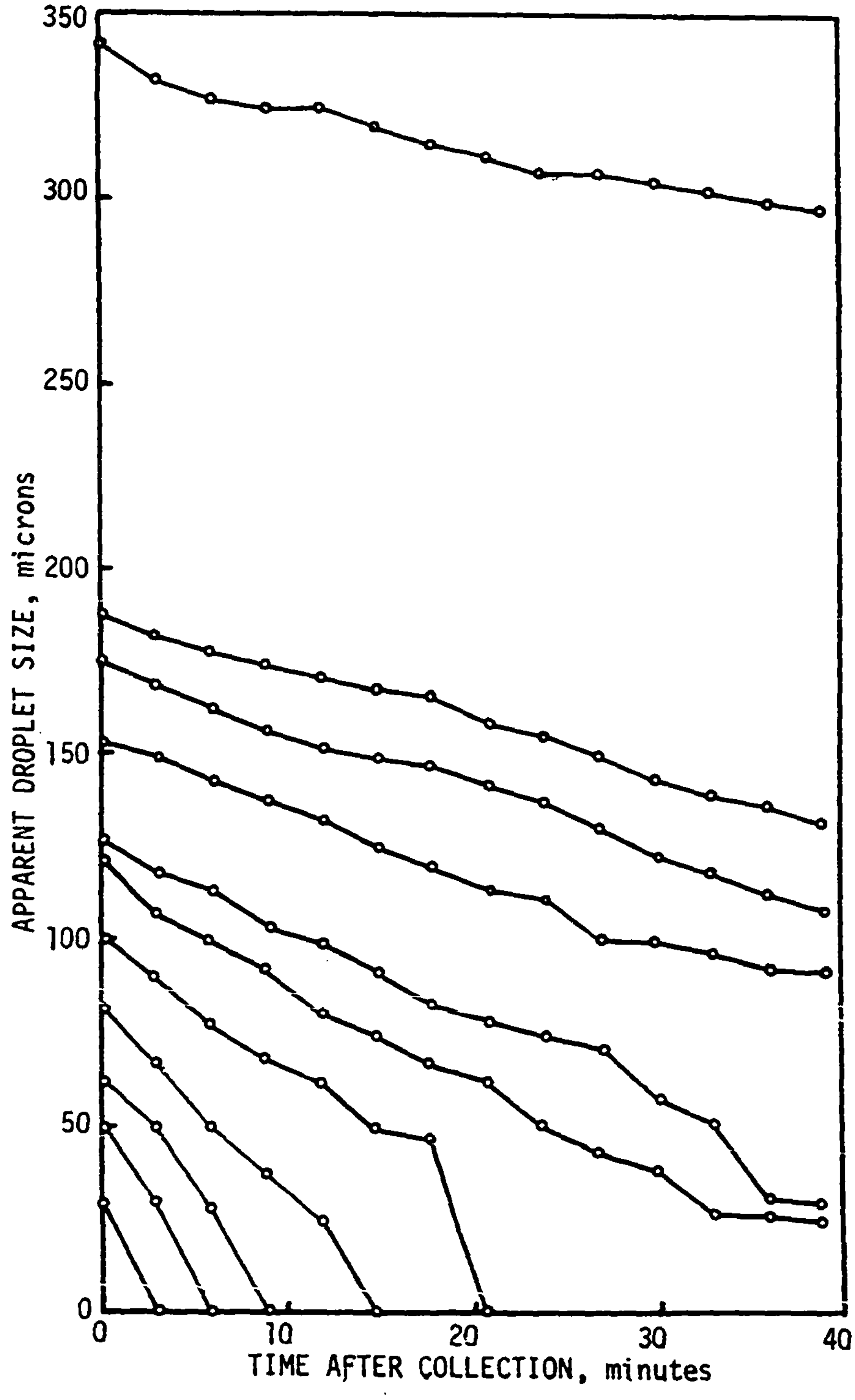

Figure 12. Effect of spray dissolution on apparent droplet size

dissolution. Apparently, the surface energy of the spray droplets was so great that water still dissolved in the naptha. The next procedure investigated was to lower the temperature of the naptha. This caused as much as a five-fold reduction in the rate of spray dissolution. If the naptha were chilled below the dewpoint of the surrounding air, atmospheric moisture would condense on the surface of the liquid, causing a haze on the surface which interferred with subsequent photography. This water haze also frequently coalesced to form large, undyed water drops, which would sink to the bottom of the cell to be photographed with the dyed spray. The undyed drops frequently resulted in a ring-shaped image when photographed, and when counted with the automatic scanning equipment caused erroneous measurements to be made.

The procedure which was finally followed was to conduct tests when the absolute humidity of the air was low, and chill the naptha to a few degrees above the dewpoint. In this way, the length of time available for photography of the sample was increased approximately four-fold.

The spray nozzles, shutter, and collection apparatus were enclosed in a tight chamber to control the environment surrounding spray. The chamber contains a plenum at the top into which air is carried by a small centrifugal blower. The partition between the plenum and the rest of the chamber is perforated to serve as a diffuser for the air, which moves vertically downward and leaves by a pipe at the center of the bottom. This pipe in turn leads to a vertical pipe, the top of which leads to a filter box and the bottom of which contains a 3 mm hole to permit liquid spray to drain from the pipe. A diagram of the chamber is shown in Figure 13, and a photograph is shown in Figure 14. The vertical velocity of the air in the chamber is approximately 1 ft/sec; this was maintained during the test to prevent accumulation of fine spray in the chamber, which would then result in a bias in the sampling of the spray.

E. Measurement of Spray Samples

After the dishes were exposed to the spray, the spray was turned off and the droplets allowed to settle to the bottom of the dish for about 15 seconds. The dish was then transferred to a flat stone block, which was suspended by three ribbons extending approximately 20 cm above it, as shown in Figure 15. The purpose of this block and its suspension, which constituted a pendulum, were to permit the dishes to be carried freely without the jiggling inherent in hand carrying of light objects. A typical sample is shown in Figure 16.

The dish was then transferred from the block to the light stand for photographing. Photographs of the spray samples were taken on 35 mm Kodalith Ortho No. 3 film. The camera used was a conventional single lens reflex 35 mm camera. A bellows was used to permit extension of the lens to permit a 2X magnification of the object on the film. The magnification was measured by focusing the camera on the scale of a vernier caliper. The size of the image at the film plane was measured on the ground glass using the dividers. The extension of the lens was then adjusted until an exact 2X magnification was achieved. The photographic apparatus used is shown in Figure 17.

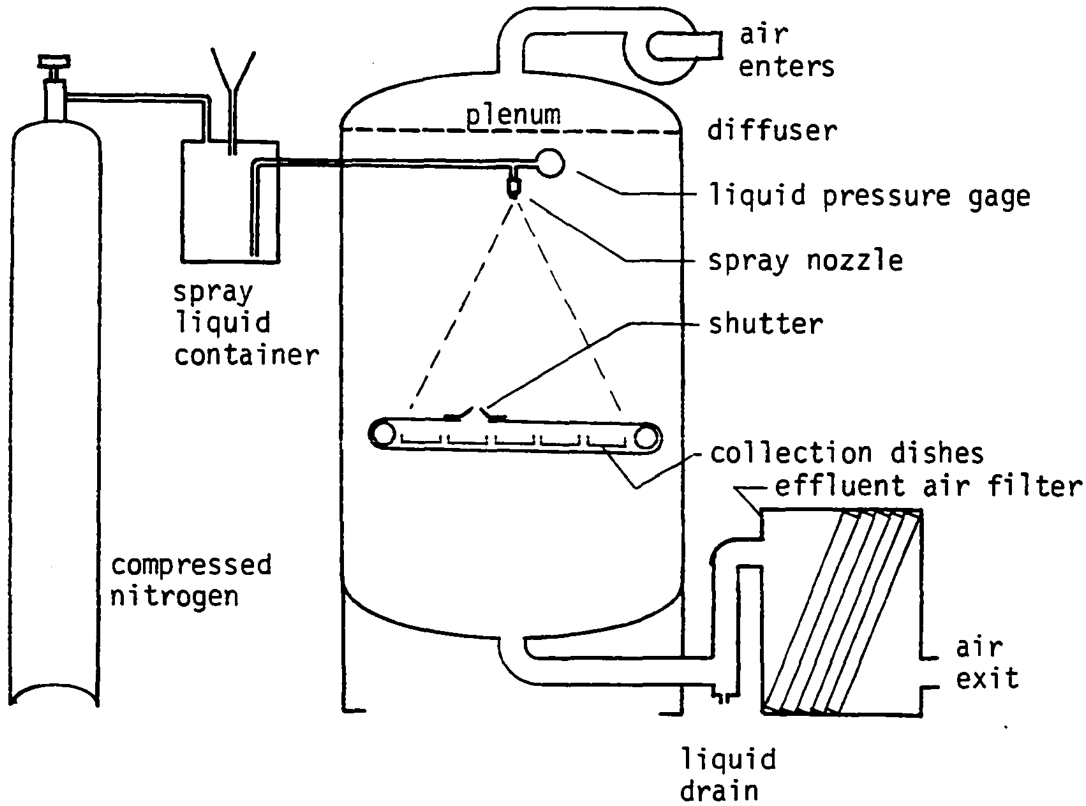

Figure 13. Diagram of spray collection apparatus

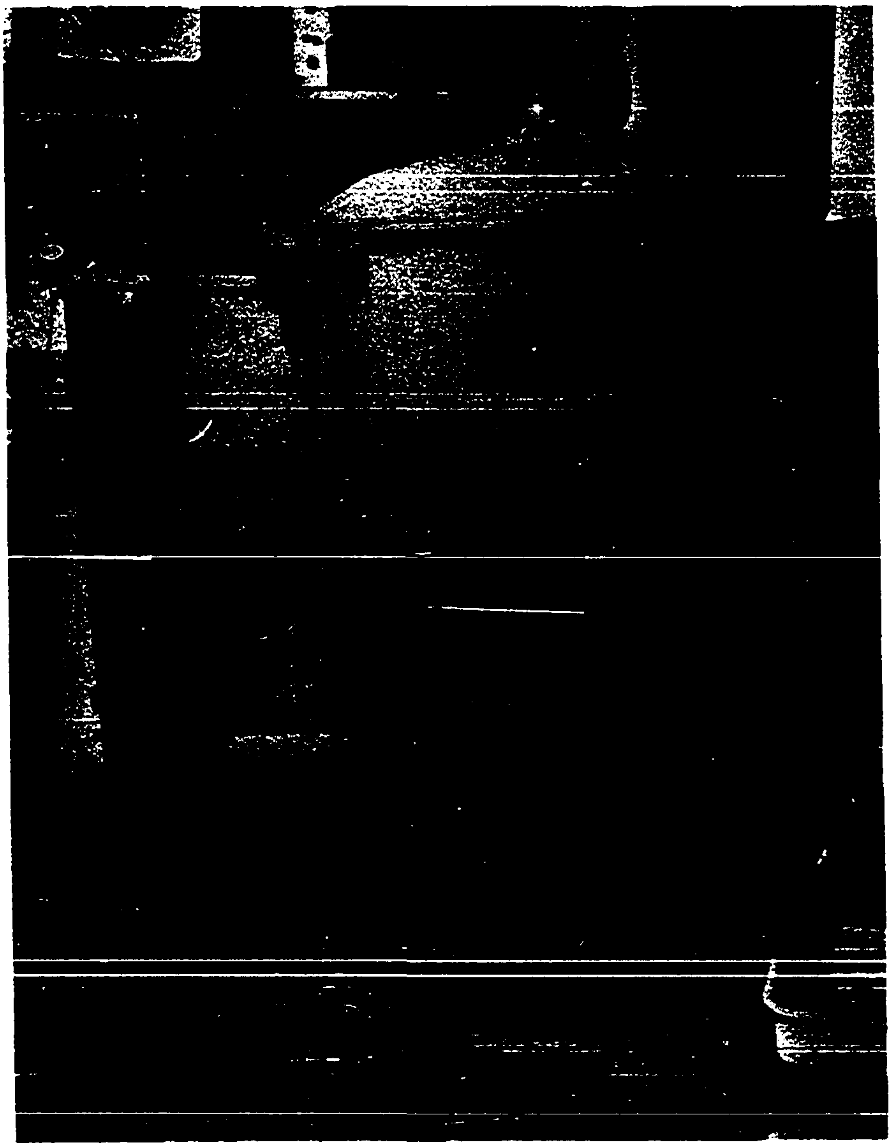

Figure 14. General view of spray collection apparatus, showing, from left to right, the nitrogen supply, insulated spray liquid tank, spray chamber, and filter box for effluent air

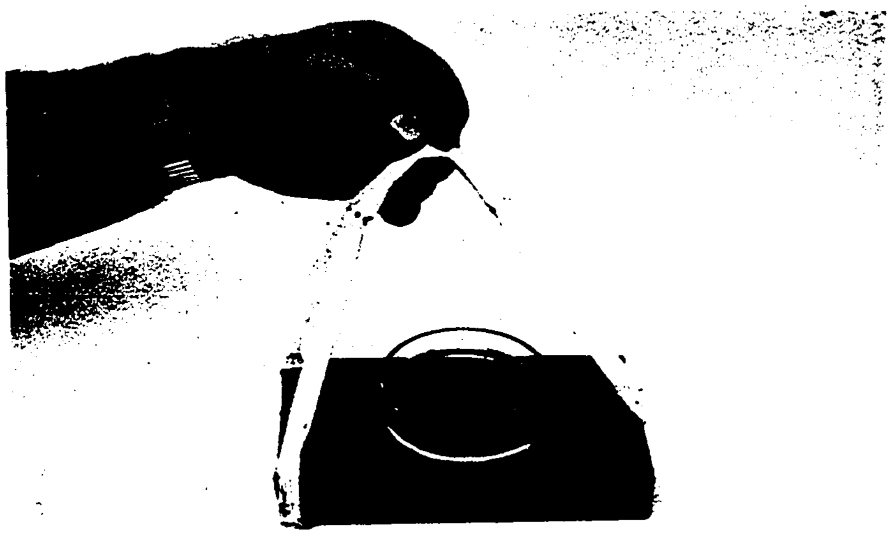

Figure 15. Method of carrying spray collected in dish of naptha on a pendulum block

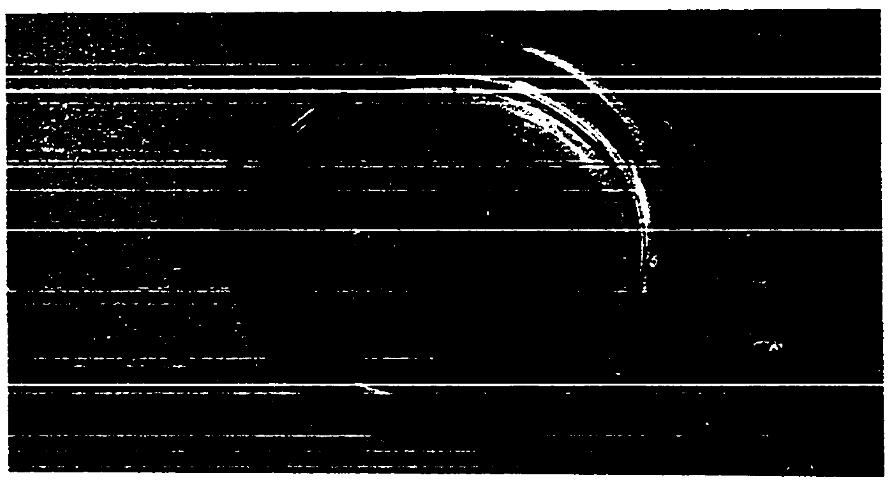

Figure 16. Typical sample of spray collected in dish of naptha

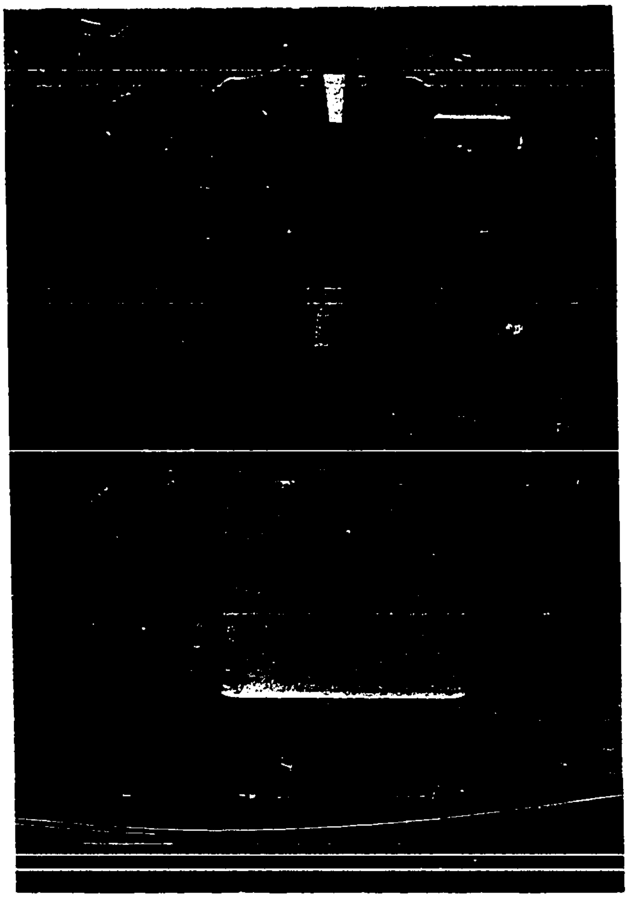

Figure 17. Apparatus used for photographing spray samples

The lens used was a 55 mm macro lens available from the camera manufacturer. A number of experiments were photographed at first using the general purpose lens provided with a camera mounted in a reverse position on Kodak high contrast high resolution film. When such films were scanned on the automatic counting equipment, however, it was found that the contrast and the resolution of this film was not sufficient to record droplets of 20 microns or smaller. These experiments were then repeated using the higher resolution film and lens.

The procedure suggested by Rupe (1949), and later used by Tate and Marshall (1953) involved filling the collecting cell (dish) to the brim with additional Stoddard solvent after the droplets had been collected, and covering the cell with an optically flat glass while being photographed. This procedure is time consuming, and the delay caused by filling the cell permits considerable dissolution of the water droplets into the solvent. To permit faster photography, the dishes were photographed uncovered, through the free liquid surface. Vibrations of the building caused small gravity waves to exist frequently on this surface, causing the image to move. The Kodalith Ortho No. 3 film has a low light sensitivity (ASA rating = 2.0) so that considerable light was required for adequate exposure of film. To prevent blurring of images by the surface waves, lighting was provided by two high intensity photographic strobe lights directed into a box painted with flat white paint. This lighting, in addition to being of high intensity and brief duration, also provides a very flat lighting when used in such a box, with resulting satisfactorily uniform illumination over the image.

Because dyed spray drops, even though they may appear to the eye to be quite dark, will transmit some light, photographs of very small spray drops may not register on high contrast film if overexposed. The lithographic type film used in this work has a very low latitude for exposure. As a result, it was found that exposure must be closely controlled to preserve drop registration and size on the films. Figures 18 and 19 show the effect of changes in several photographic variables on the resulting measurements obtained.

Similar care and control was necessary in the development of film. The film was developed in Kodalith Ortho developer for 2-1/2 minutes at 20°C. The temperature of the developer could not be permitted to vary more than ±0.5°C, nor could the development time vary more than 5 seconds without variations in the size of image recorded on the film.

Using one roll of film, five photographs were taken of each of the five sample dishes, or a total of 25 photographs for each experiment. Another photograph was taken of the experiment number and other experimental conditions on one frame of the film to provide a permanently attached record to prevent confusion of films. A diagram of the system for photographing the sample is shown in Figure 20.

An exception to this system was made for samples taken from experiments with 15° and 40° fan angle nozzles. In such cases, the sampling system was as shown in Figure 21 and 22, respectively.

The size of the droplet images on film were then counted in different size classes using a flying spot scanner. The general principles of operation of this scanner have been described by Mansberg (1964). In

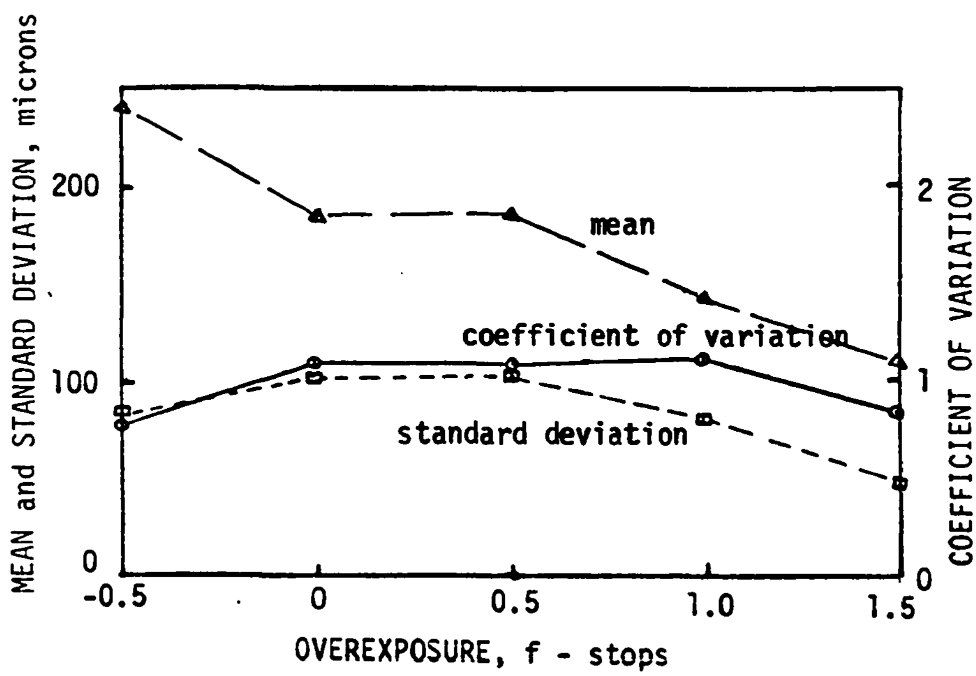

Figure 18. Effect of varying film exposure on droplet size measurements

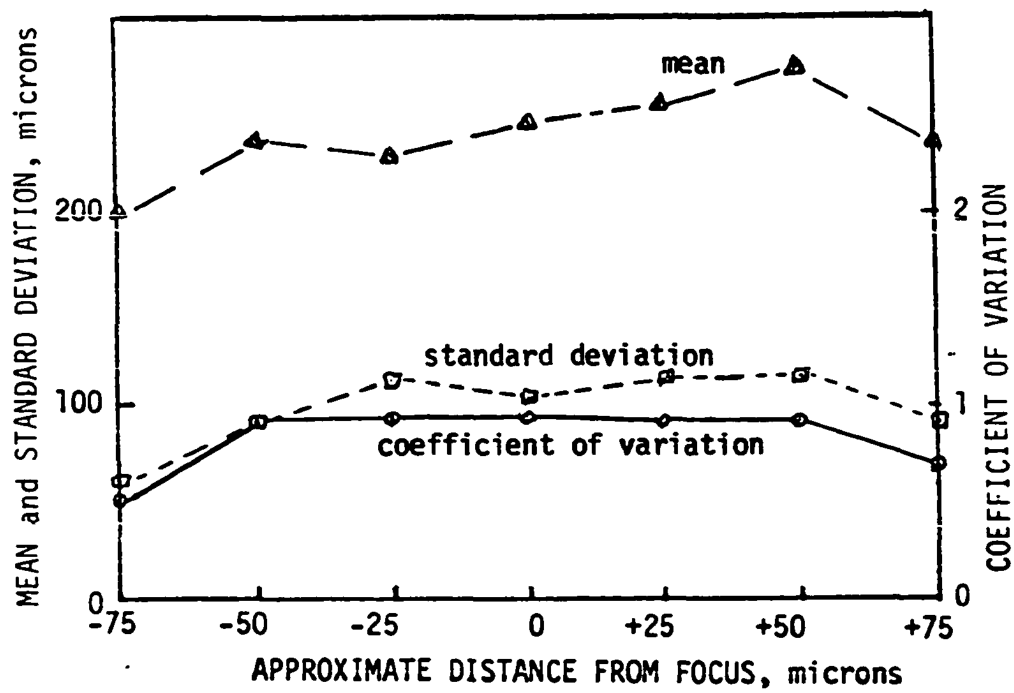

Figure 19. Effect accuracy of focus on droplet size measurements

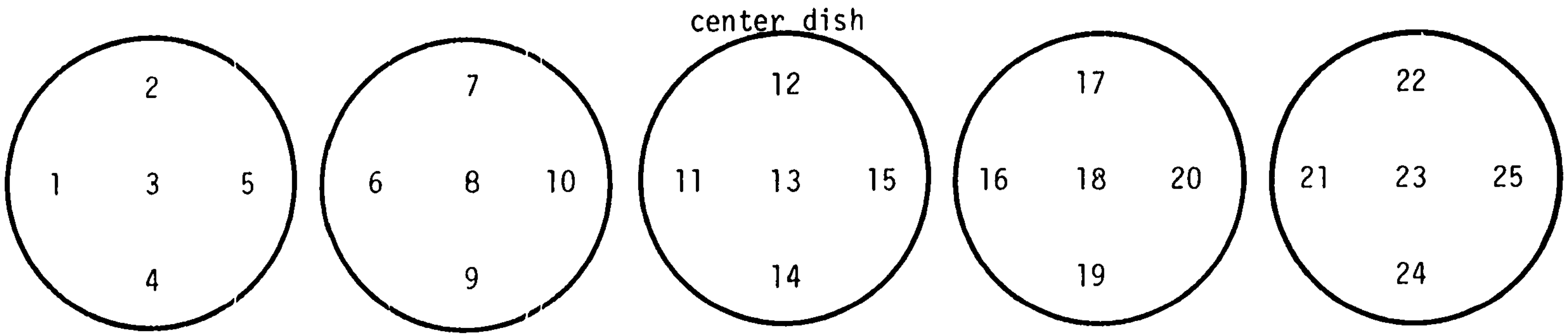

Figure 20. Sampling system on 65°, 80°, and 110° fan angle nozzles

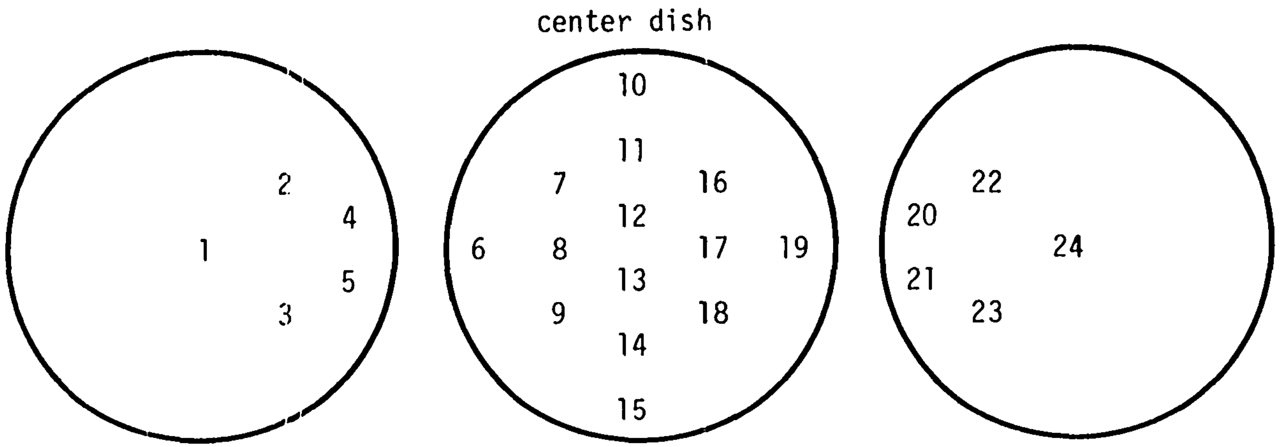

Figure 21. Sampling system used on 10° fan angle nozzles

center dish

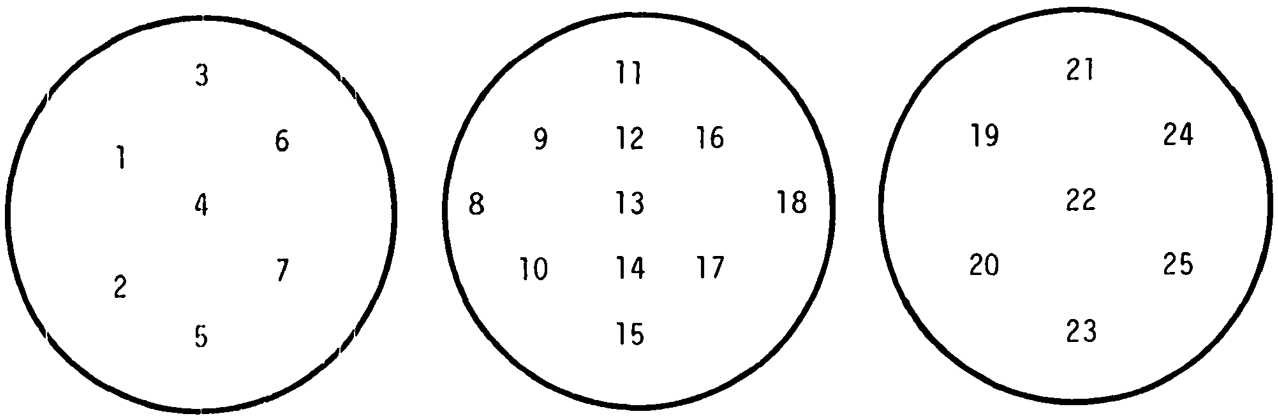

Figure 22. Sampling system used on 40° fan angle nozzles

general, this instrument can be set to count the number of circular images on film which are greater than 20k microns diameter, where k = 1, 2, 3 ..., 1,000. Because such a wide choice of size classifications was possible, it was necessary to choose a practical set of classifications for this study. Because of the general logarithmic normal distribution of spray, a set of size classifications was chosen which increased in increment as the classification size increased. The classifications chosen are listed in Table 4. As a 2X drop to film image magnification took place during photography, the spray droplet size classifications are equal to one-half of the classifications listed in Table 4. The

Table 4. Upper limits of film image size classifications, microns

20	140	320	640	1280	2560	4960
40	160	360	720	1440	2880	5520
60	180	400	800	1600	3200	6080
80	200	460	920	1840	3600	6720
100	240	520	1040	2080	4000	7360
120	280	580	1160	2320	4480	8000

counts made with the flying spot scanner were punched onto machine tabulating cards by an on-line card punch while the counts were made, so that reduction of data could be made with automatic data processing equipment.

A computer program was then written which caused the computer to read the data recorded on these cards, sum the data from all photographs for each experiment, and subtract counts in sequence to provide the number distribution as a function of the size of classifications used. The program further caused the computation of the statistics given in Equation 2, 3, 5, 6, 7, 8, 12, 13, 14, and 15. The computer program for these calculations is shown in Appendix A. Appendix B describes the testing procedure used for this program. The program further printed out the drop size distribution for each experiment and the statistics computed for each experiment. The distribution data for each experiment is shown in Appendix C. The resulting distribution data and statistics were also punched onto tabulating cards suitable for further computation or machine plotting.

F. Simplified Measurement Techniques

A further objective of our work was to develop a method for measuring droplet size and variability which would circumvent the usual size classification process used in most particle sizing operations. It was believed that such a system might save time for future researchers measuring droplet sizes and computing descriptive statistics.

The motivation for pursuing this objective results from the problem faced by research workers involved in collecting low density droplet samples which are counted and measured with flying spot scanner equipment. Each photograph may show only a few droplets. If such samples are scanned with flying spot scanning equipment, the length of time required to scan each sample is fixed. To obtain accurate estimates of drop size statistics, a certain minimum number of drops must be counted, which requires many photographs to be scanned. This requires an excessive amount of time for counting and sizing of such samples on automatic counting equipment. This time could be greatly reduced if counts and calculations based upon size classifications were unnecessary.

One such approach is described by the following line of reasoning. Say that a sample of circles exists on the surface, having varying diameters, D, having a frequency distribution, f (D). The first moment of the distribution about the origin D = 0 is defined as

$$\mu_1' = \Sigma D f(D) \tag{22}$$

likewise the second moment is

$$\mu_2' = \Sigma D^2 f(D) \tag{23}$$

By definition the mean of f(D) is $\mu = \mu_1'$ and it can be shown that $\mu_2' = \mu^2 + \sigma^2$, where σ^2 is the variance of f (D).

From a sample of n circles, the sum of diameters, L, is

$$L = n \Sigma D f(D) \tag{24}$$

and the sum of the areas of the circles, A_s, would be

$$A_s = n \Sigma (D^2\pi/4) f(D) \tag{25}$$

equating integrals yields the simplified mean, D_{the}

$$D_{the} = \mu = L/n \tag{26}$$

and equating the other corresponding integrals yields

$$\frac{4\ A_s}{n\ \pi} = \mu^2 + \sigma^2 \tag{27}$$

or

$$\sigma^2 = \frac{4\ A_s}{n\ \pi} - \frac{L^2}{n^2} \tag{28}$$

and we will write

$$s_{the} = \sigma = \left[\frac{4\ A_s}{n\ \pi} - \frac{L^2}{n^2}\right]^{1/2} \tag{29}$$

We see from this that it may be possible to get a measure of the mean and variance of F (D) directly from measures of A_s, L, and n, without measuring the drop distribution in discrete size classes, and that this can be done without any assumption, or knowledge, of the form of the size distribution, F (D).

Fortunately, estimates of A_s, L, and n can be obtained quickly from photographic films of drop samples using the flying spot particle counter. This can be seen by inspection of Figure 23, a schematic diagram of the mode of operation of the flying spot particle counter. As the cathode ray tube image scans the ith particle, it is evident that the sum of the diameters is approximately

$$L = \sum_{i=1}^{n} D_i = \delta_r\ n_{ch} \tag{30}$$

and the sum of the areas is approximately

$$A_s = \sum_{i=1}^{n} A(D_i) = \delta_p\ \delta_r\ n_p \tag{31}$$

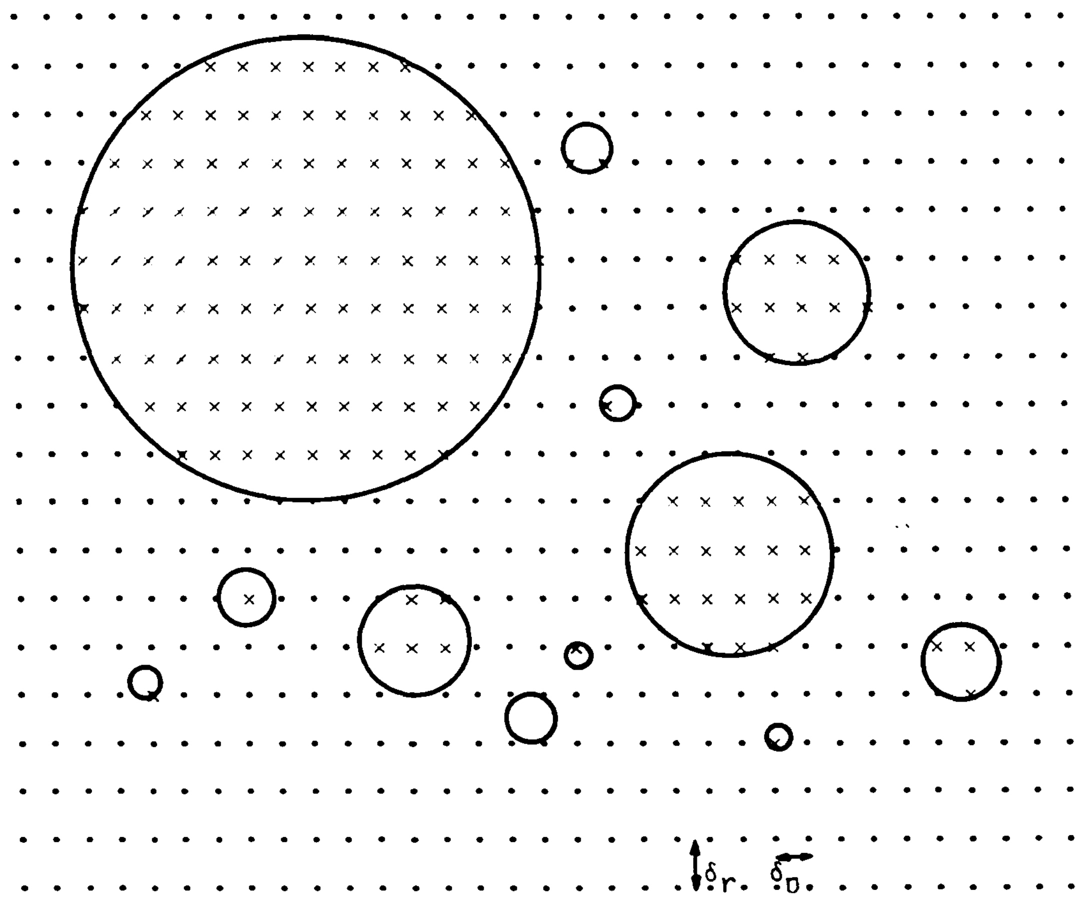

Figure 23. Schematic diagram of geometric relationship between raster lines, clock pulses, and droplet images on film being scanned in the flying spot particle counter

where n_{ch} = total number of chords intercepted, n_p = total number of pulses in the intercepted chords, δ_r = the spacing of the scan lines in the cathode ray tube raster, and δ_p = the spacing, on the raster line, of the clock pulses used to measure chord length.

To determine if these relationships actually hold in practice, n_{ch} and n_p were measured for all samples of spray droplets taken in this study. A section of the computer program shown in Appendix A computed A_s and L using Equations 30 and 31, also computed the mean and variance of the sample using Equations 26 and 29.

V. RESULTS

The principal statistics computed from the measurements taken with the flying spot counter are tabulated in Appendix D and E. As indicated on the table, certain planned experiments could not be conducted because spray would not form under the conditions established for the experiment. Several other experiments were unproductive because the samples taken from the experiments contained too great a droplet population to be accurately counted with the flying spot counter. Some such experiments were repeated, yielding films of samples which were successfully counted. Finally, data are also included on several tests which are replicates of tests in the basic experimental plan.

These data were, in turn, used for computing various dimensionless ratios $\bar{D}/A^{1/2}$, as well as the other independent dimensionless variables in Equation 18, using the computer program listed in Appendix F. In order to understand this program, it should be borne in mind that the data for operating conditions for each experiment were read in the units which were measured during the experiment. Thus, pressure was read in lb/in.^{2}, and nominal nozzle angle was measured in degrees, while the remaining operating variables were measured in standard gm-cm-sec metric units. The data from this program were intended to be used for computer plotting of results. The program used for plotting on the local computer would not accommodate logarithmic scales having values less than one.

Consequently, all values of $\overline{D}/A^{1/2}$ were multiplied by 1,000 during this computation.

A. Dispersion Statistics

The results of the experiments are presented in dimensionless form in Appendix H and I. This is the first point at which one is able to see some measures of the relative uniformity of droplet sizes. The coefficient of variation ranges from approximately 0.56 to 1.09, the volume weighted coefficient of variation ranges from 0.45 to 1.53, the geometric standard deviation ranges from 0.44 to 1.12, and the volume weighted geometric standard deviation ranges from 0.34 to 0.72. The relationship among these statistics, and their relationship to operating conditions is discussed later, but the general values are pointed out here, as they constitute a reference against which other spray devices, intended for the production of uniform spray, must be compared.

B. Effect of Design and Operating Variables

Values of $\overline{D}/A^{1/2}$ were plotted as functions of $p\ A^{1/2}/\sigma$ and $p^{1/2}\ \rho^{1/2}\ A^{1/2}/\mu$. An example of such a plot is shown in Figure 24. A distinct dependence upon $p\ A^{1/2}/\sigma$ is evident from this plot, but no clear dependence upon $p^{1/2}\ \rho^{1/2}\ A^{1/2}/\mu$ can be discerned, either by inspection or by regression analysis. However, further inspection of the data and the resulting graphs indicated that distinctly different results were obtained with the three different sizes of nozzles used for the

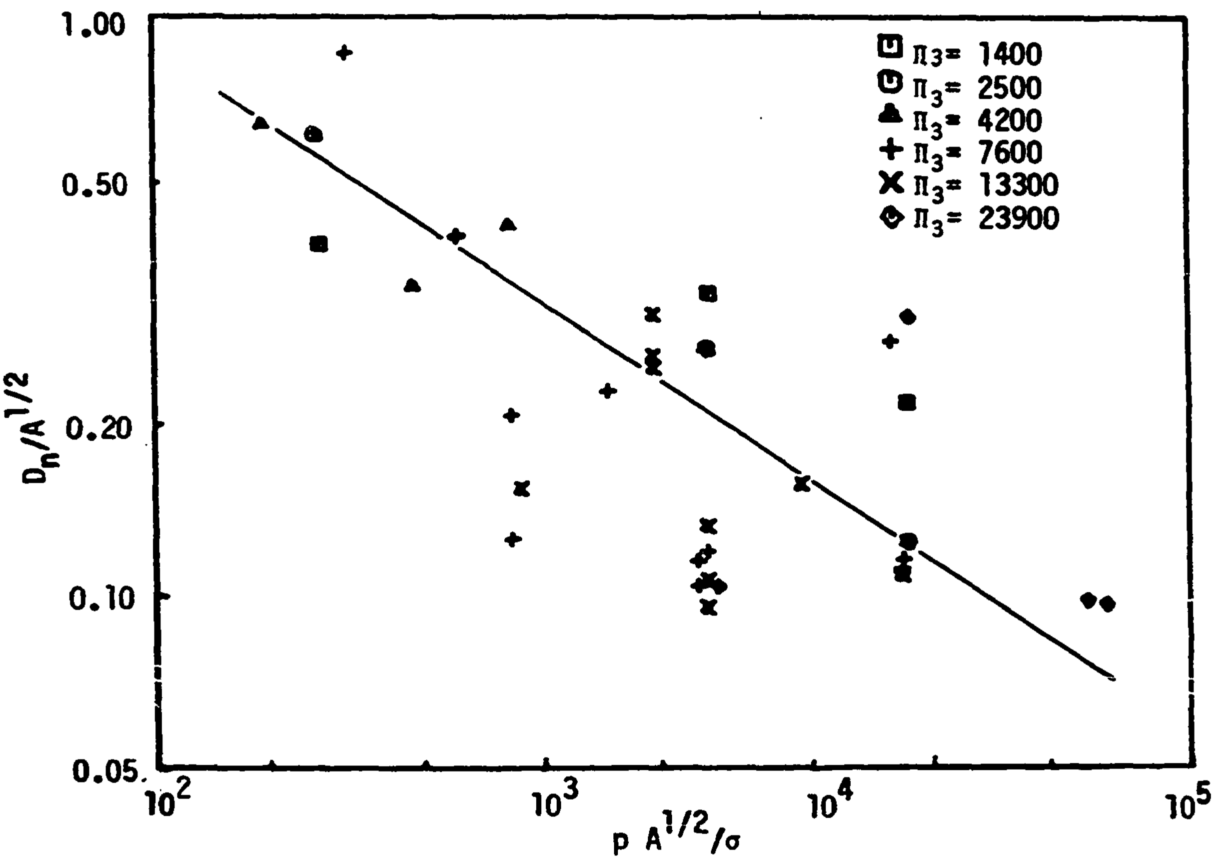

Figure 24. $D_n/A^{1/2}$ as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$

experiments. Consequently $\overline{D}/A^{1/2}$ was further plotted as a function of $p\ A^{1/2}/\sigma$ and the nozzle sizes. The results of these plots are shown in Figures 25 through 29. The effect of orifice size appears to exist even though values of $p^{1/2}\ \rho^{1/2}\ A^{1/2}/\mu$ are equal. That is, the effect of orifice size cannot be accounted for by variations in $p^{1/2}\ \rho^{1/2}\ A^{1/2}/\mu$.

No fully satisfactory explanation can be advanced for this effect of orifice size. No other variable has been previously reported which might account for such a large difference in results of experiments conducted under identical conditions of $p\ A^{1/2}/\sigma$ and $p^{1/2}\ \rho^{1/2}\ A^{1/2}/\mu$. For example, the density in this variable changed little and seem unlikely to have caused such a large effect. Conversely, the liquid was forced through the nozzle in all experiments by gas pressure in the spray liquid container. Liquid issuing from the nozzle at high pressures may have had a greater amount of dissolved nitrogen which would come out of solution, forming bubbles, as the liquid pressure dropped going through the orifice. However, this result would have caused the curve for small nozzles to lie below the curve for large nozzles, which is the opposite of that represented by the experimental data.

It is possible that biases introduced by the spray collection and sampling process might have produced such a result. Deposition of the finer spray onto the surface of the collecting liquid by inertial impaction would be less than that of the coarser spray (which is produced by the largest nozzles). This would produce a sample from fine spray which is coarser than the true population. Likewise, dissolution of the spray droplets into the collecting liquids would produce a sample mean larger than that of the original population. Both of these biases, however, have

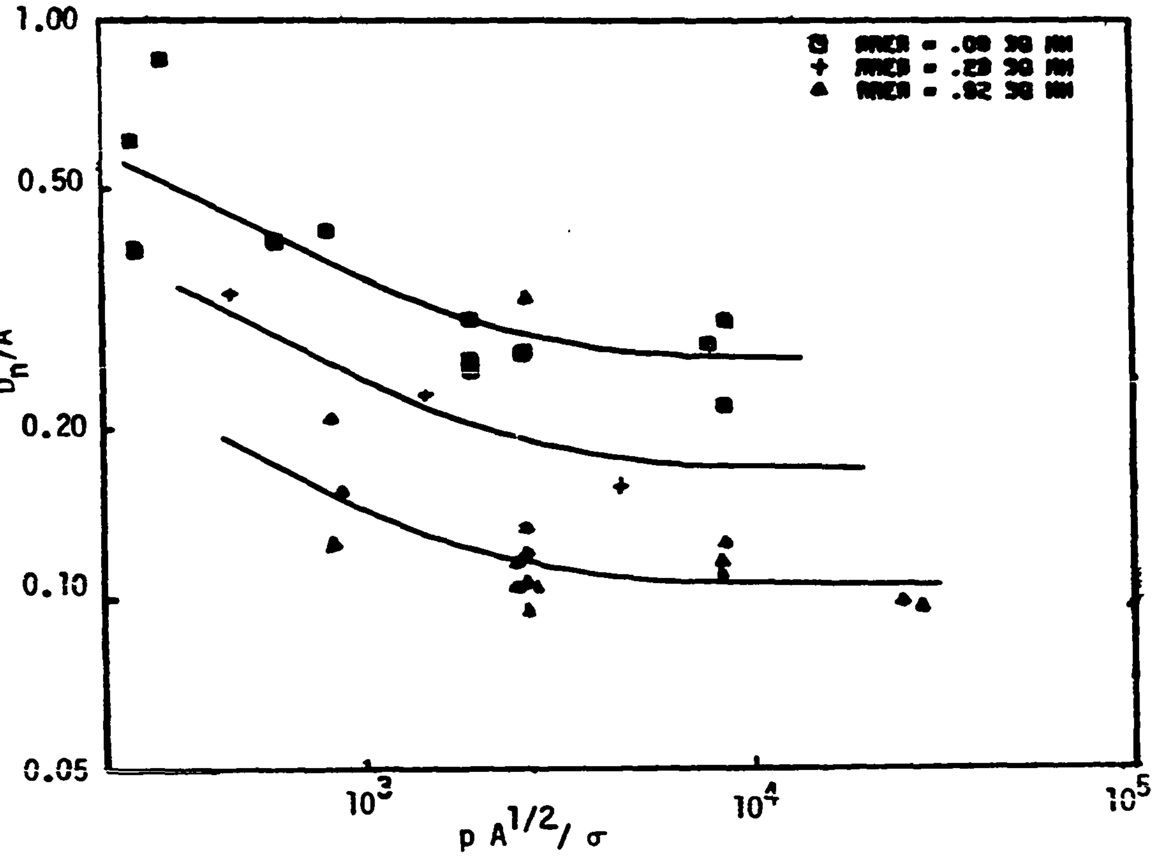

Figure 25. $D_n/A^{1/2}$ as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of A

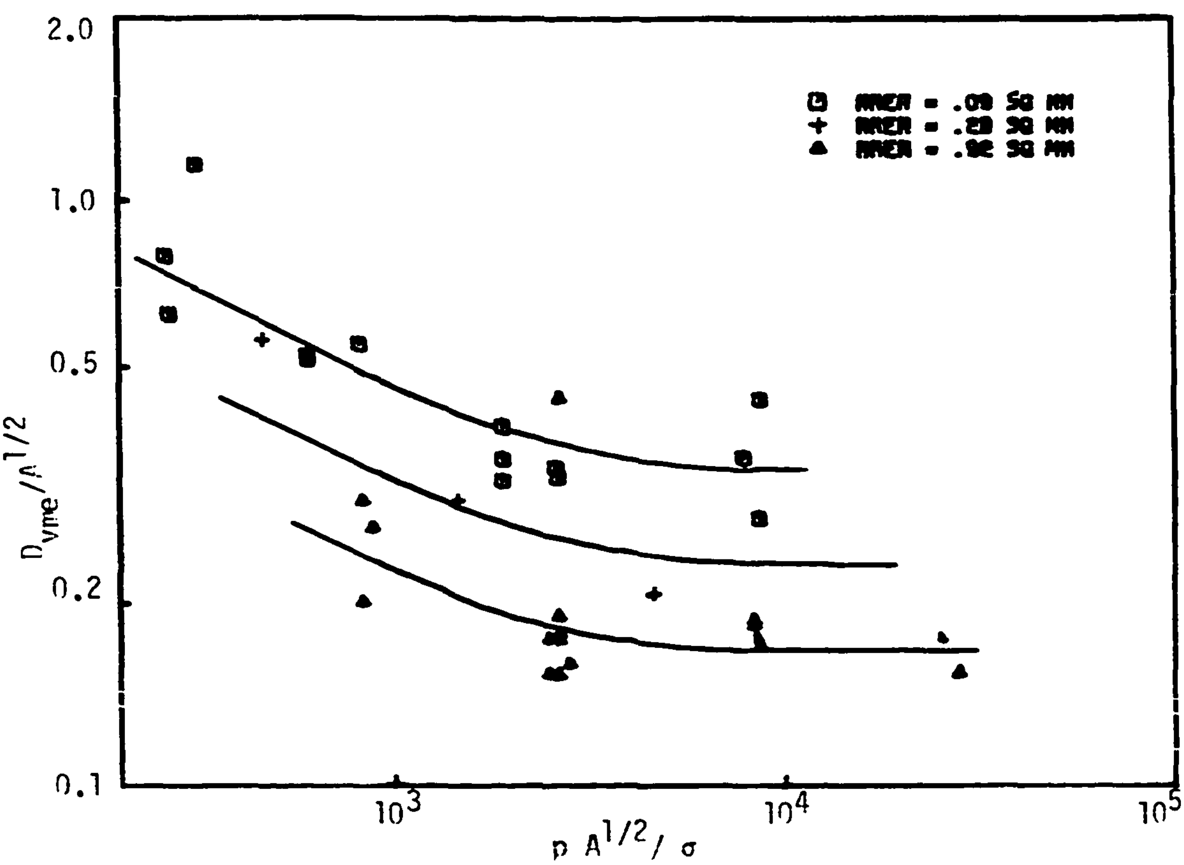

Figure 26. $D_{VME}/A^{1/2}$ as a function of p $A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of A

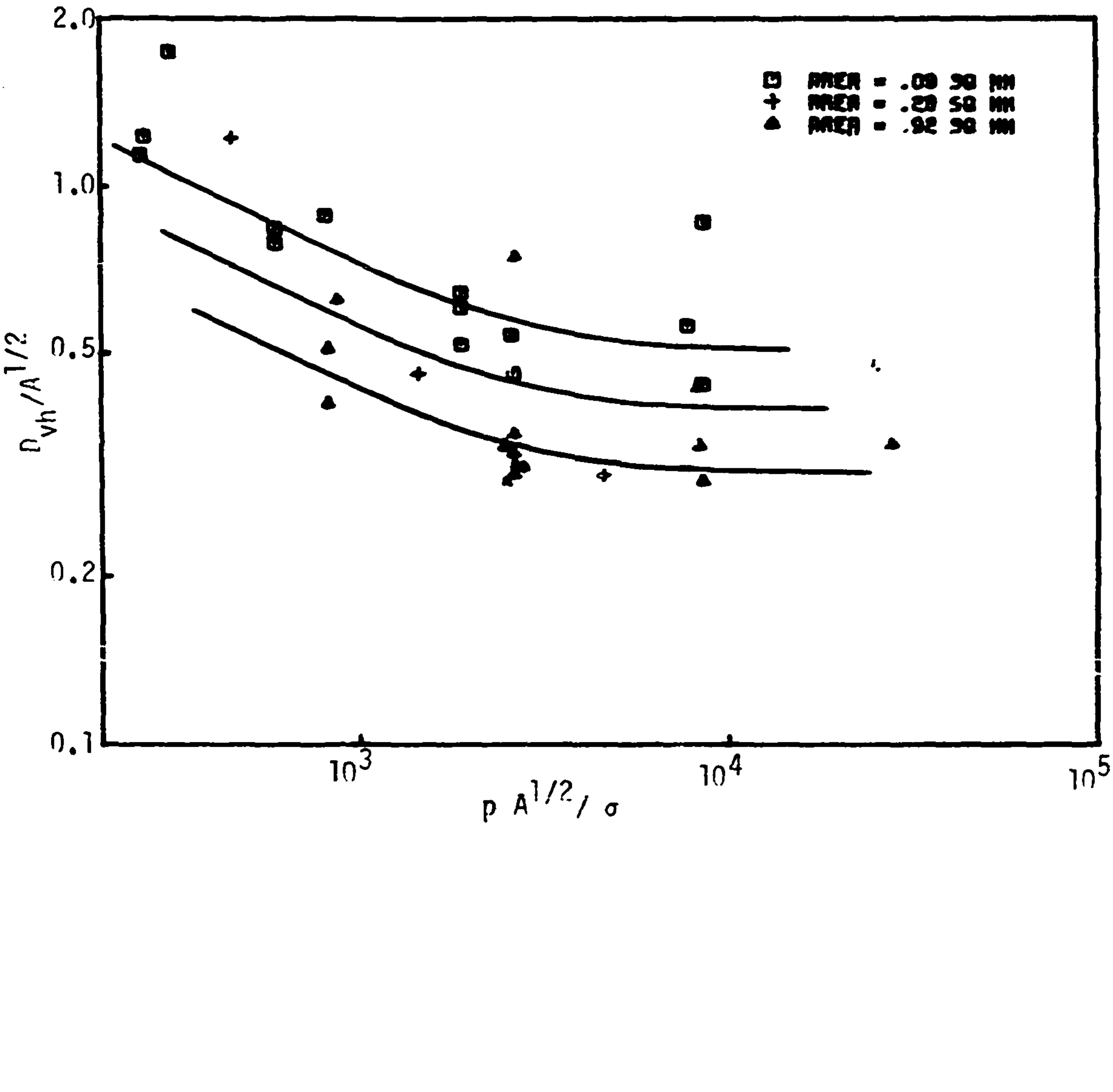

Figure 27. $D_{VH}/A^{1/2}$ as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of A

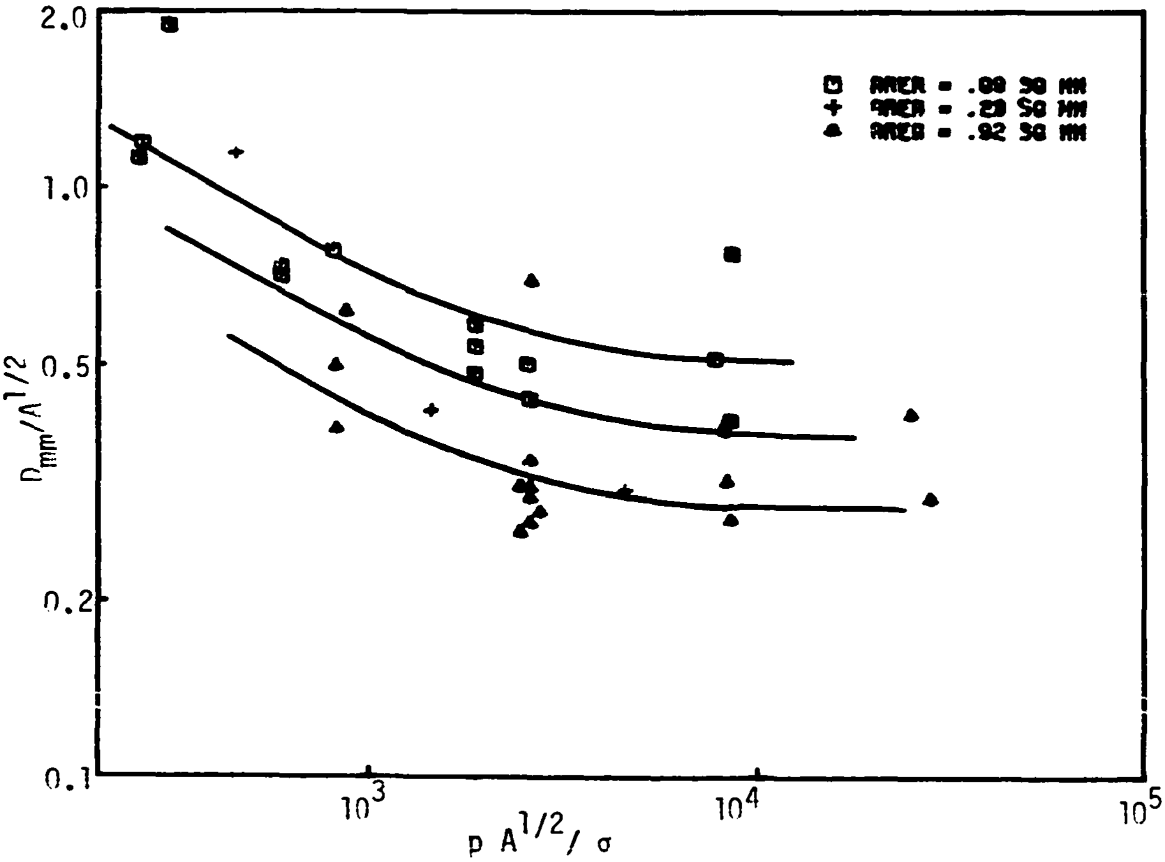

Figure 28. $D_{MM}/A^{1/2}$ as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of A

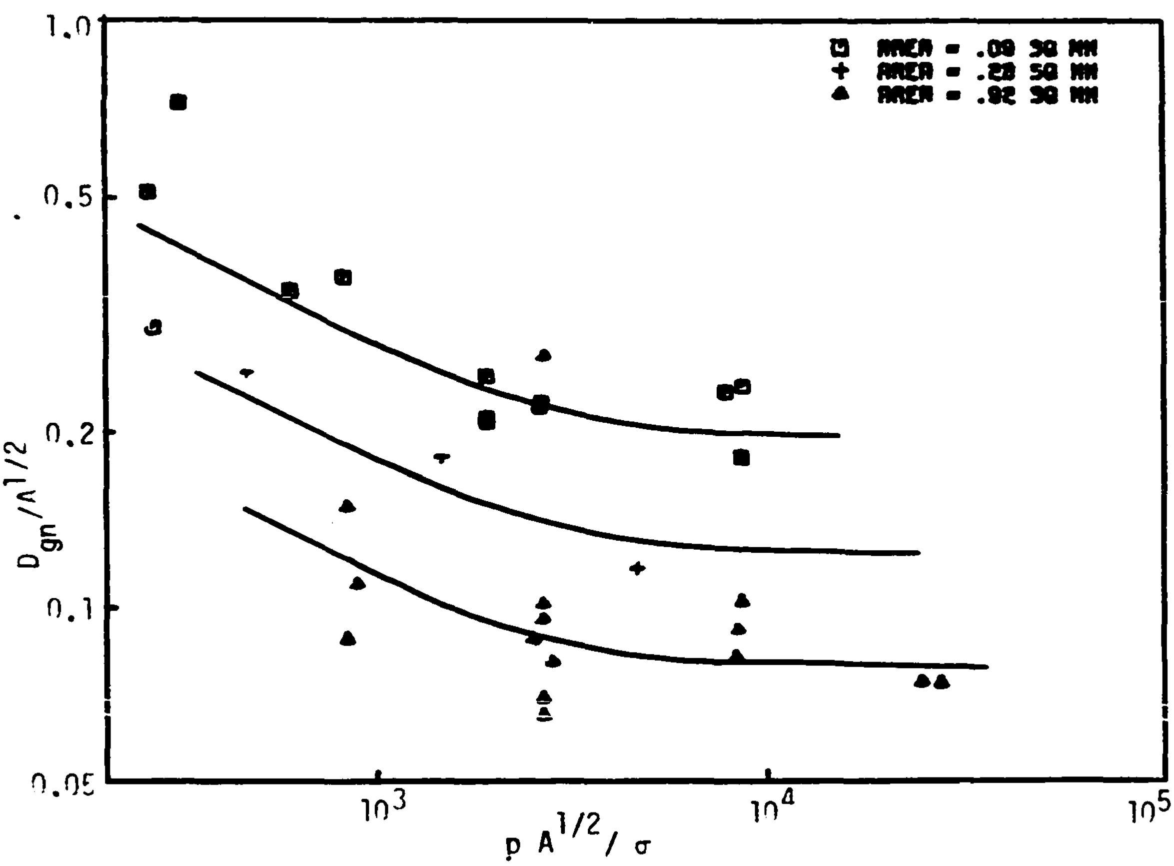

Figure 29. $D_{gN}/A^{1/2}$ as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of A

been present to some extent in the collecting and sampling methods used by previous investigators, who have not reported such a distinct effect of nozzle size.

It is also possible that the lack of exact geometric similarity between large and small nozzles may be sufficient to yield different results. Figures 30 and 31 show enlargements made from the photomicrographs of nozzle orifices which were used to measure orifice cross-sectional areas. It appears that the small orifice is somewhat more rounded on the ends of the oval opening than is the case with the larger orifice. The sharp corners at the end of the larger orifice may produce a small segment of thinner liquid sheet, which breaks up into fine spray, which is lacking in the case of the smaller nozzle. Again, however, such differences, although unreported, are likely to have existed in the nozzles in previously reported research, where the effect on droplet size was missing.

Although one would wish to present the results of these experiments in completely dimensionless form, this cannot be done at the present. Attribution of the different results among different size nozzles to any of the effects discussed above is still speculative, as no measures of the variables involved were made.

Figures 32 and 33 show the additional effect of nominal spray fan angle on droplet size. Values of the arithmetic mean, D_n, are not affected by θ, while there is a definite effect upon the volume mean, D_{VH}. This is somewhat surprising at first, but D_{VH} is the integral of quite a different function than D_n.

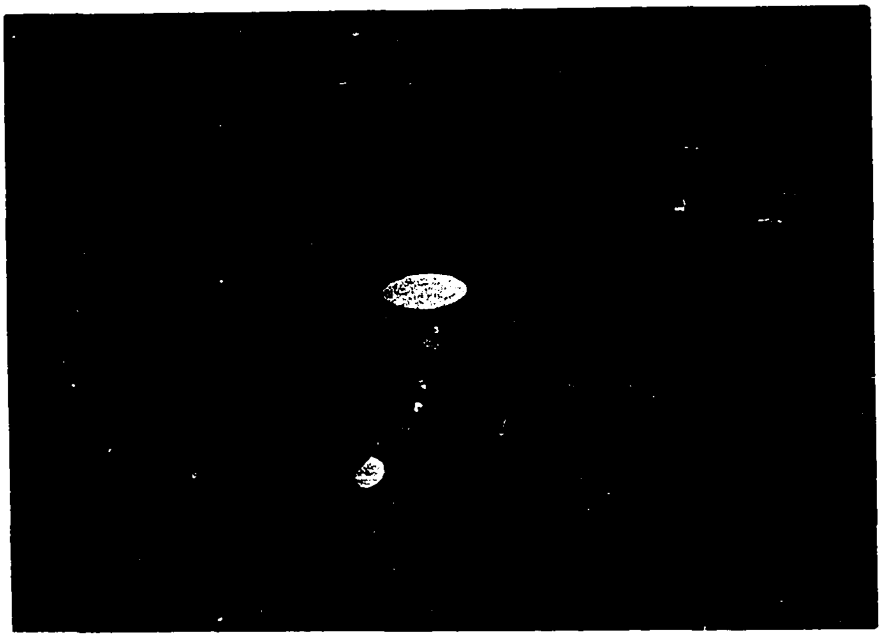

Figure 30. 20X magnification photograph of 0.09 mm^2 nozzle orifice

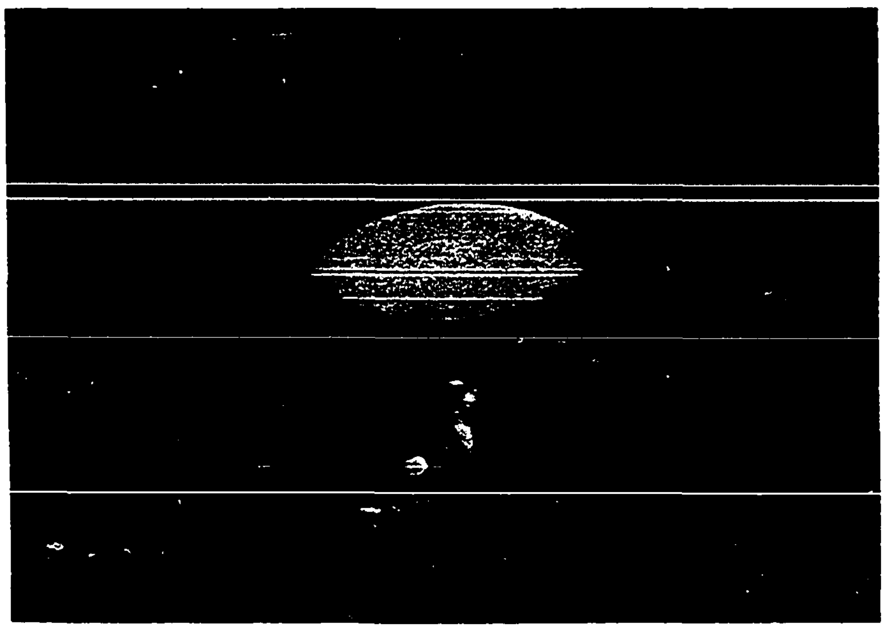

Figure 31. 20X magnification photograph of 0.92 mm^2 nozzle orifice

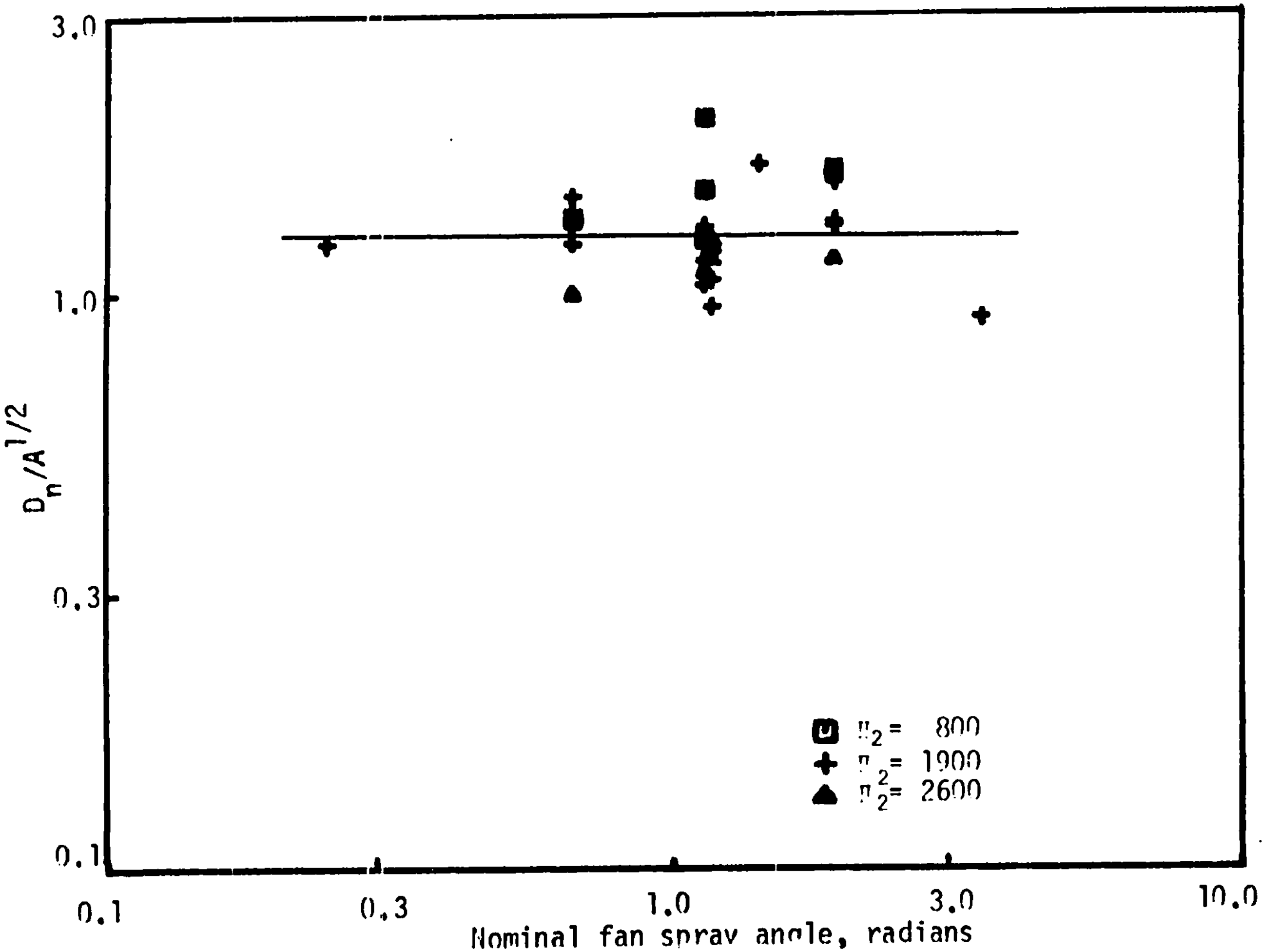

Figure 32. $D_N/A^{1/2}$ as a function of θ at differing levels of $p\ A^{1/2}/\sigma$

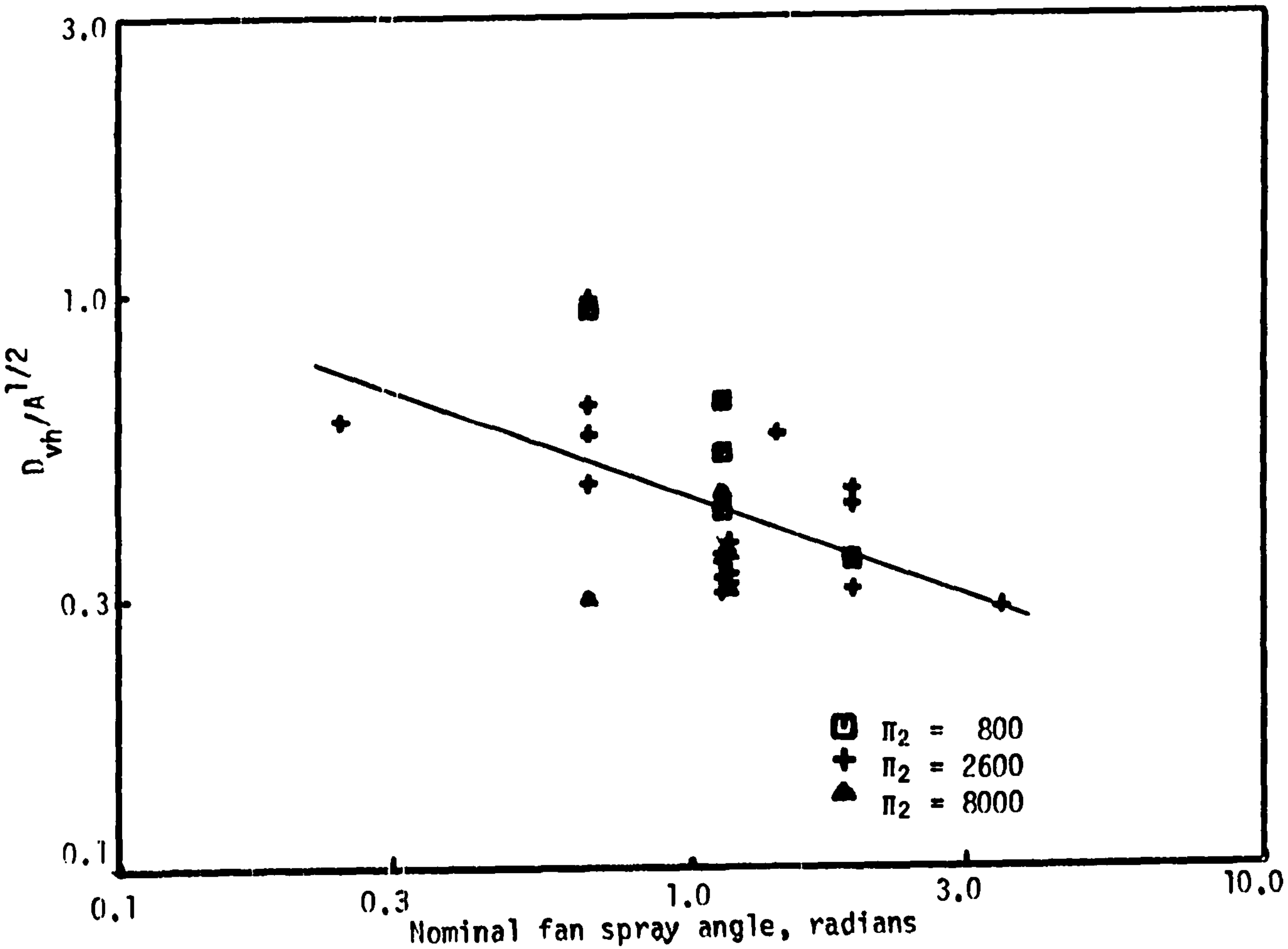

Figure 33. $D_{VH}/A^{1/2}$ as a function of θ at differing levels of $p\ A^{1/2}/\sigma$

From the indications given by the previous graphs, one can propose a form for Equation 18. Because considerable scatter exists in all of the plots of dimensionless variables, any extensive work in fitting an explicit mathematical form to the data would probably be misleading at this point. Although the work by Dorman (1952) shown in Equation 20 as well as that of Fraser et al. (1957) shown in Equation 21 both indicated a simple inverse power relationship, these data appear to show a leveling out in the value of $\bar{D}/A^{1/2}$ at $p\ A^{1/2}/\sigma = 2600$. This suggests a relationship of the form:

$$\Pi_1 = C_1\ \Pi_4^{C_2}\ (1 - C_3\Pi_2^{C_4})\ A^{C_5} \tag{32}$$

or

$$\bar{D}/A^{1/2} = C_1\theta_4^{C_2}\ (1 - C_3(p\ A^{1/2}/\sigma)^{C_4})\ A^{C_5} \tag{33}$$

This can be systematically fitted to the experimental data by establishing a dummy variable $\Pi_1 A^{-C_5}\theta^{-C_2} - C_1$. The value of C_1, C_2 and C_5 can be visually estimated from the graphs, after which C_3 and C_4 can be solved directly by regression. Better values of C_1, C_2, and C_5 can then be obtained by trial and error to minimize variance from the data, or by an optimum search technique in the space of C_1, C_2, C_3, C_4, and C_5 to minimize χ^2.

Using this procedure yields the relationships:

$$D_n/A^{1/2} = 0.109\ A^{-0.38}\ (1+13.77(p\ A^{1/2}/\sigma)^{-0.33}) \tag{34}$$

$$D_{vh}/A^{1/2} = 0.298\ \theta^{-0.33}\ A^{-0.25}\ (1+80.9(p\ A^{1/2}/\sigma)^{-0.40}) \qquad (35)$$

where the dimension of A is mm^2.

Likewise plots of coefficients of variation for constant nominal fan angle are plotted as functions of $p\ A^{1/2}/\sigma$ and $p^{1/2}A^{1/2}\rho^{1/2}/\mu$ in Figures 34 and 35. From inspection it was seen from similar plots that the geometric standard deviations s_{gn} and s_{gv} were not related to the coefficients of variation, although theoretically they should be if the distributions are logarithmic normal (Aitchison and Brown, 1957). The absence of such relationship in the statistics computed in this study implies that there was a poor fit of the distribution data to the log normal function.

Figures 36 and 37 show the coefficient of variation of the number and volume distribution as a function of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$ at various levels of $p\ A^{1/2}/\sigma$. Figures 38 and 39 also indicate the effect, at constant levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$, of varying fan angle. Nothing on these plots would suggest a functional relationship more complex than simple powers of $p\ A^{1/2}/\sigma$, $p^{1/2}A^{1/2}\rho^{1/2}/\mu$, and θ.

Thus, the specific form of Equation 19 would be:

$$s_N/D_N = 0.323\ (p\ A^{1/2}/\sigma)^{0.047}(p^{1/2}A^{1/2}\rho^{1/2}/\mu)^{0.06}\ \theta^{-0.136} \qquad (36)$$

$$s_{VH}/D_{VH} = 0.062\ (p\ A^{1/2}/\sigma)^{0.124}(p^{1/2}A^{1/2}\rho^{1/2}/\mu)^{0.185}\ \theta^{-0.146} \qquad (37)$$

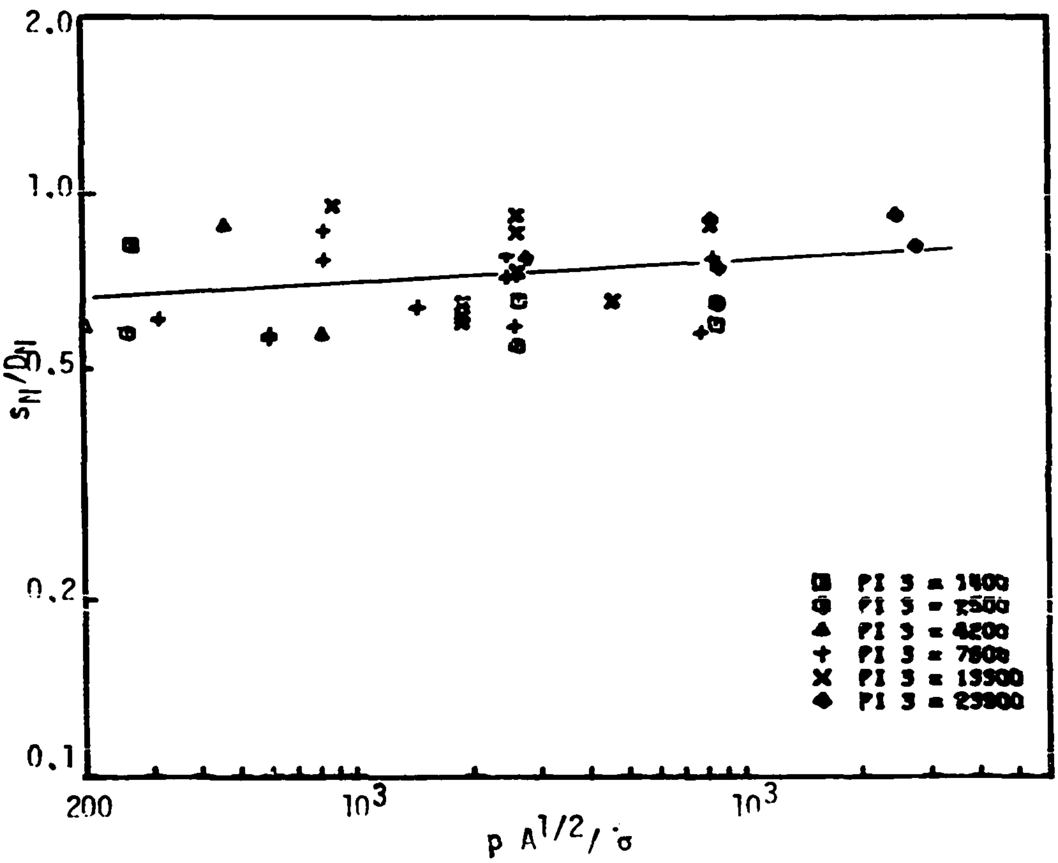

Figure 34. s_N/D_N as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$

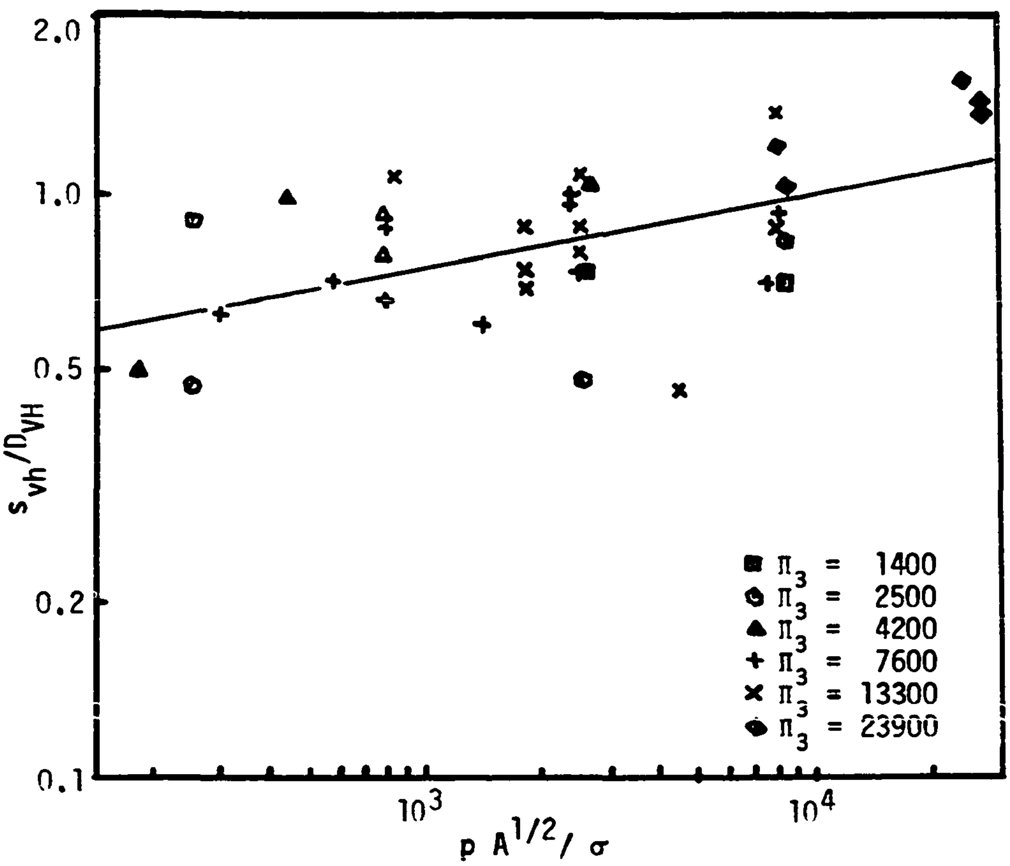

Figure 35. s_{VH}/D_{VH} as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$

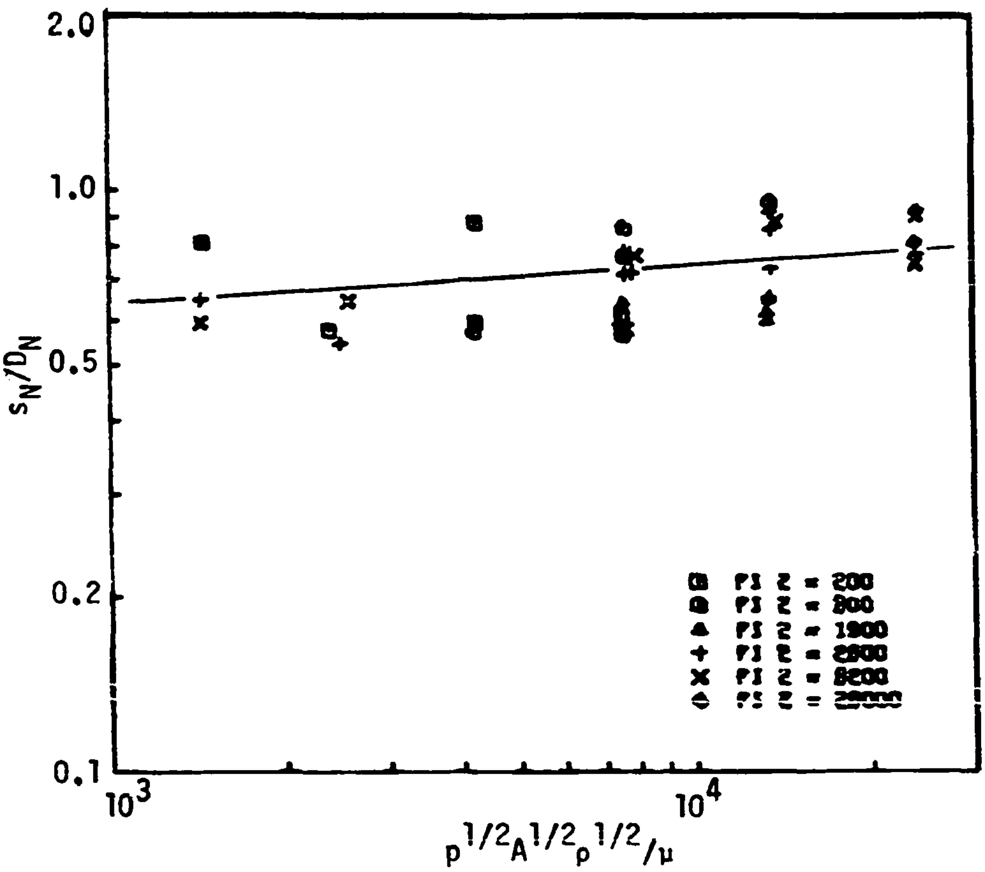

Figure 36. s_N/D_N as a function of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$ for 65° nominal fan angle nozzles, at differing levels of $p\,A^{1/2}/\sigma$

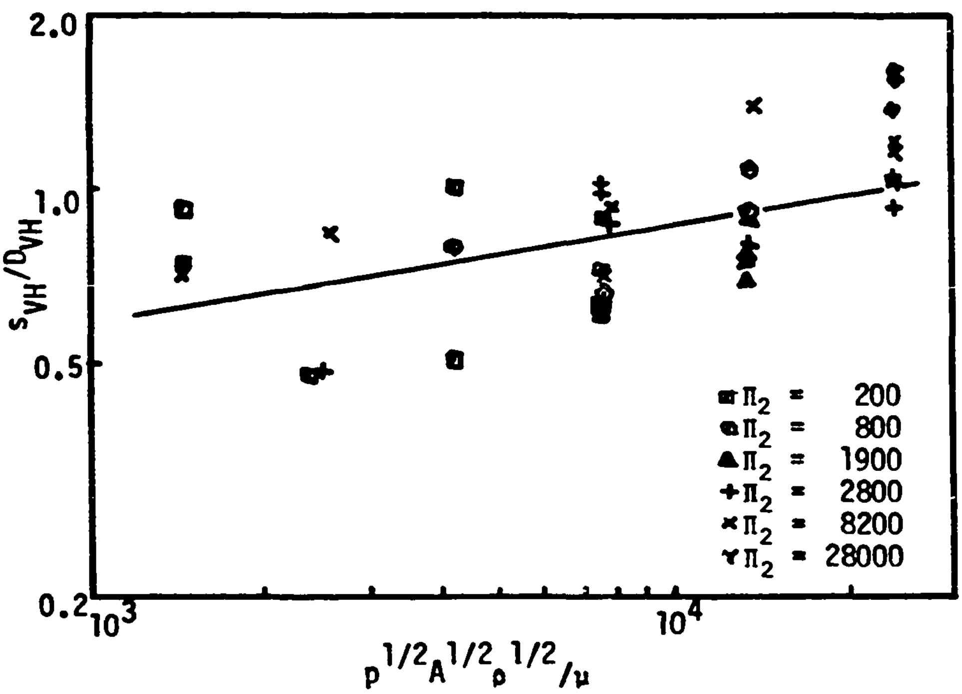

Figure 37. s_{VH}/D_{VH} as a function of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$ for 65° nominal fan angle nozzles, at differing levels of $p\ A^{1/2}/\sigma$

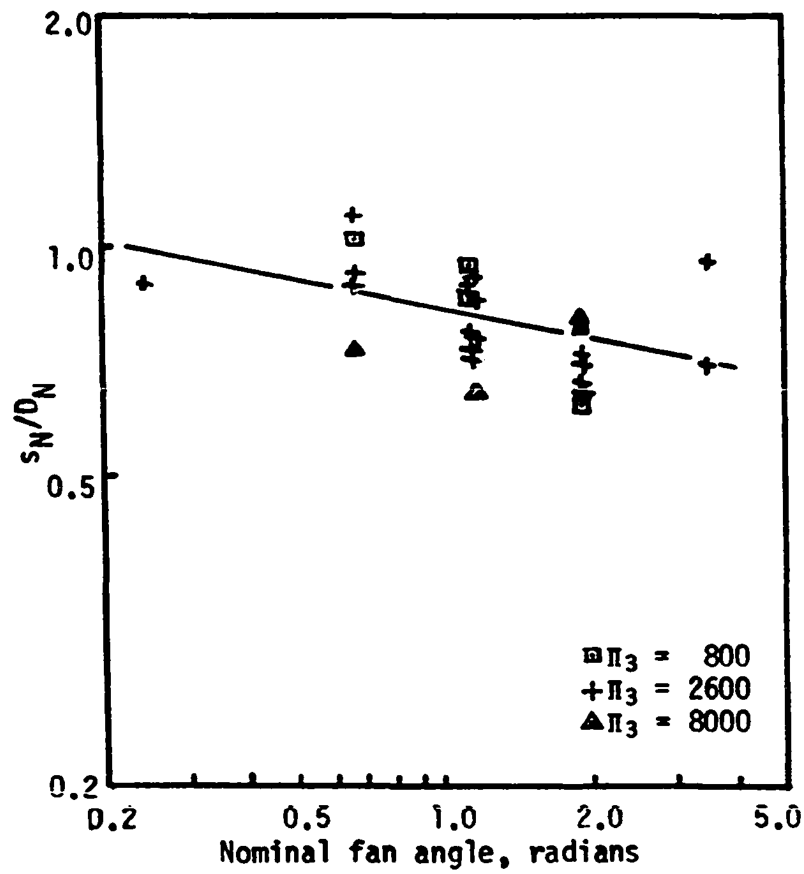

Figure 38. s_N/D_N as a function of Θ at differing levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$

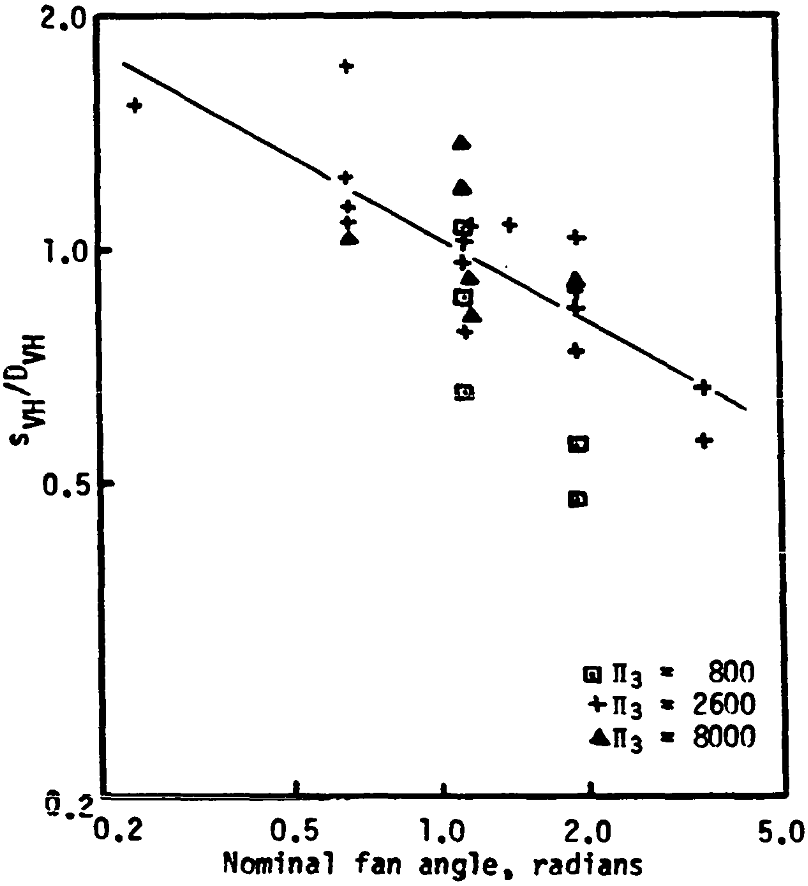

Figure 39. s_{VH}/D_{VH} as a function of θ at differing levels of $P^{1/2}A^{1/2}\rho^{1/2}/\mu$

C. Simplified Measurement Technique

To determine the value of simplified statistics based on summed drop diameter and summed drop areas, estimates of the statistics derived from classified data were plotted against the simplified statistics. The plots for mean diameters are shown in Figures 40 through 46. The unweighted statistics, that is, D_n and D_{gn}, appear to be predicted more accurately by this simplified statistic than do the volume weighted statistics. This is understandable, since the volume weighted statistics reflect other properties of the distribution, being related to higher moments of the distribution.

Close inspection of the data seems to reveal that the accuracy of prediction might be related to the size of the samples used for the measurements. To determine if this was so, the ratio D_n/D_{nthe} was computed for each test and plotted as a function of the number of droplets used in the test in Figure 47. This shows such an effect does exist, and that the best relationship between the statistics based on classified data and those based upon the simplified measurements likely exist for a droplet sample of about 2,500 drops. This would only be plausible if the effect were, in fact, due to the crowding, or lack of it, of the samples on the film which was counted. Since 25 samples were usually taken, this would indicate the best drop density per frame would be approximately 100 drops. Higher numbers of droplets per frame result in portions of some drops intercepting the margins of the counting area. Such cases will tend to distort the relationship between the two statistics, since the simplified statistic is based on the assumption of circular images.

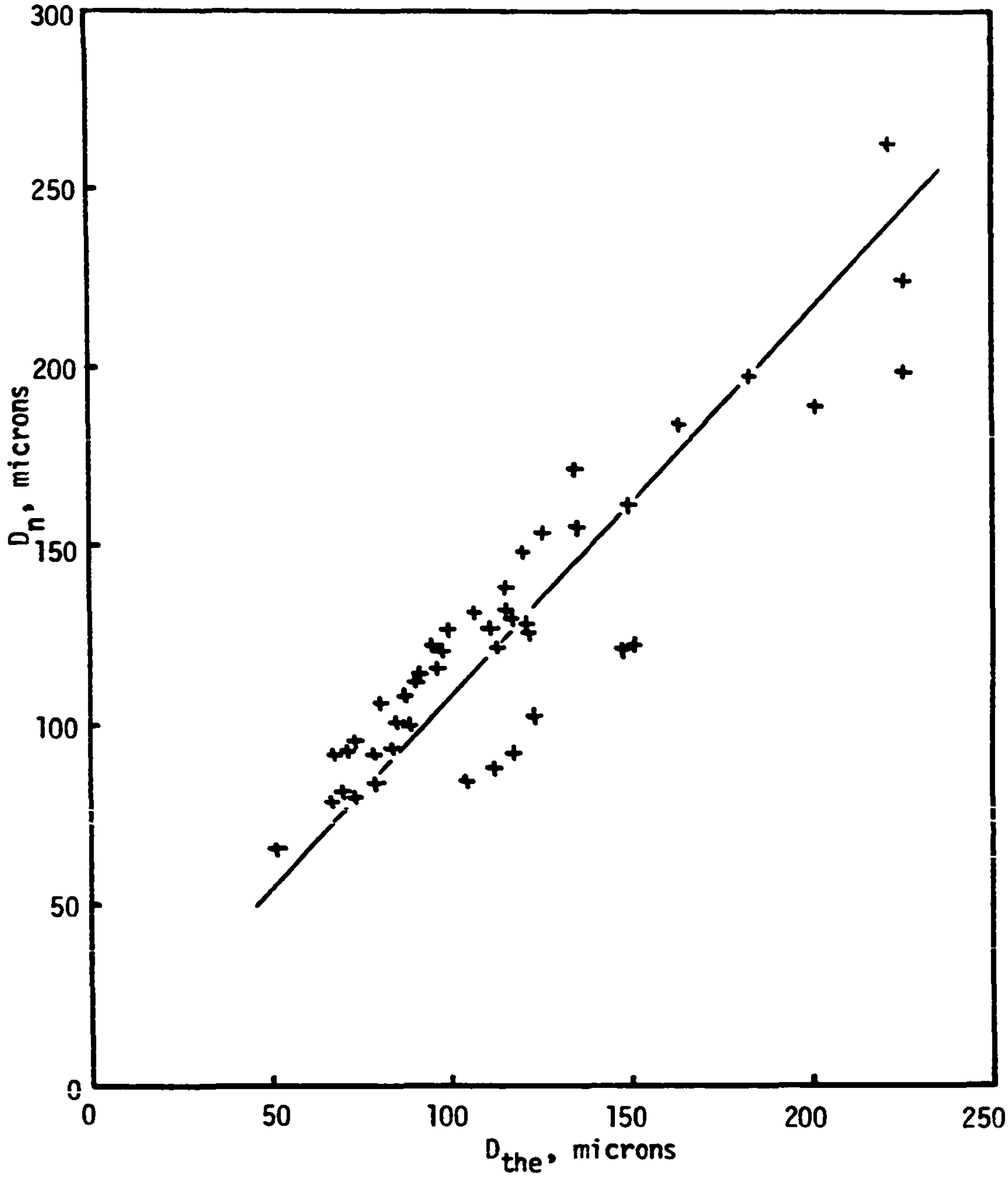

Figure 40. Correlation of D_N and D_{the}

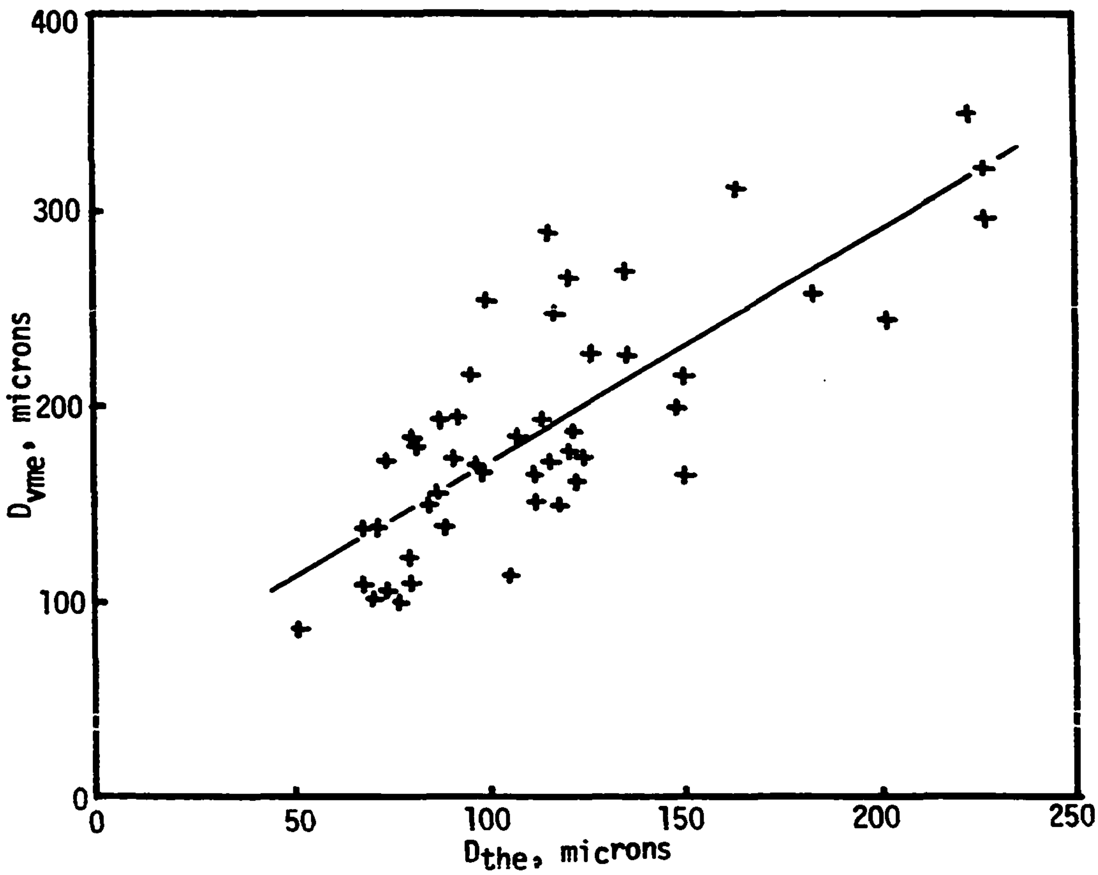

Figure 41. Correlation of D_{VME} and D_{the}

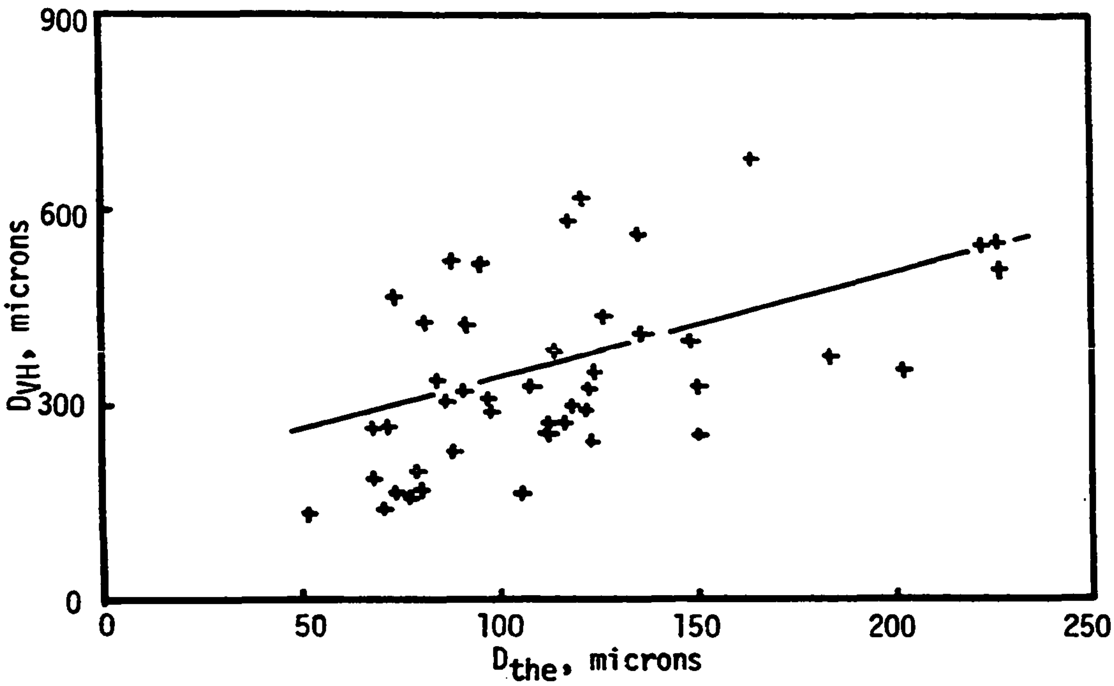

Figure 42. Correlation of D_{VH} and D_{the}

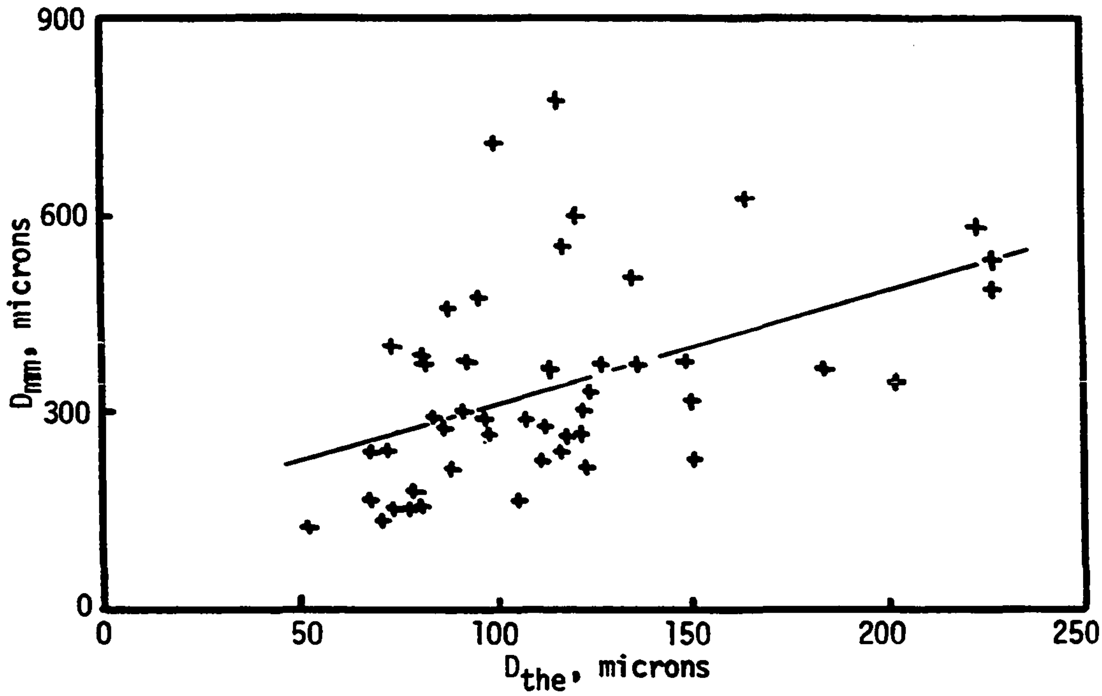

Figure 43. Correlation of volume median diameter and D_{the}

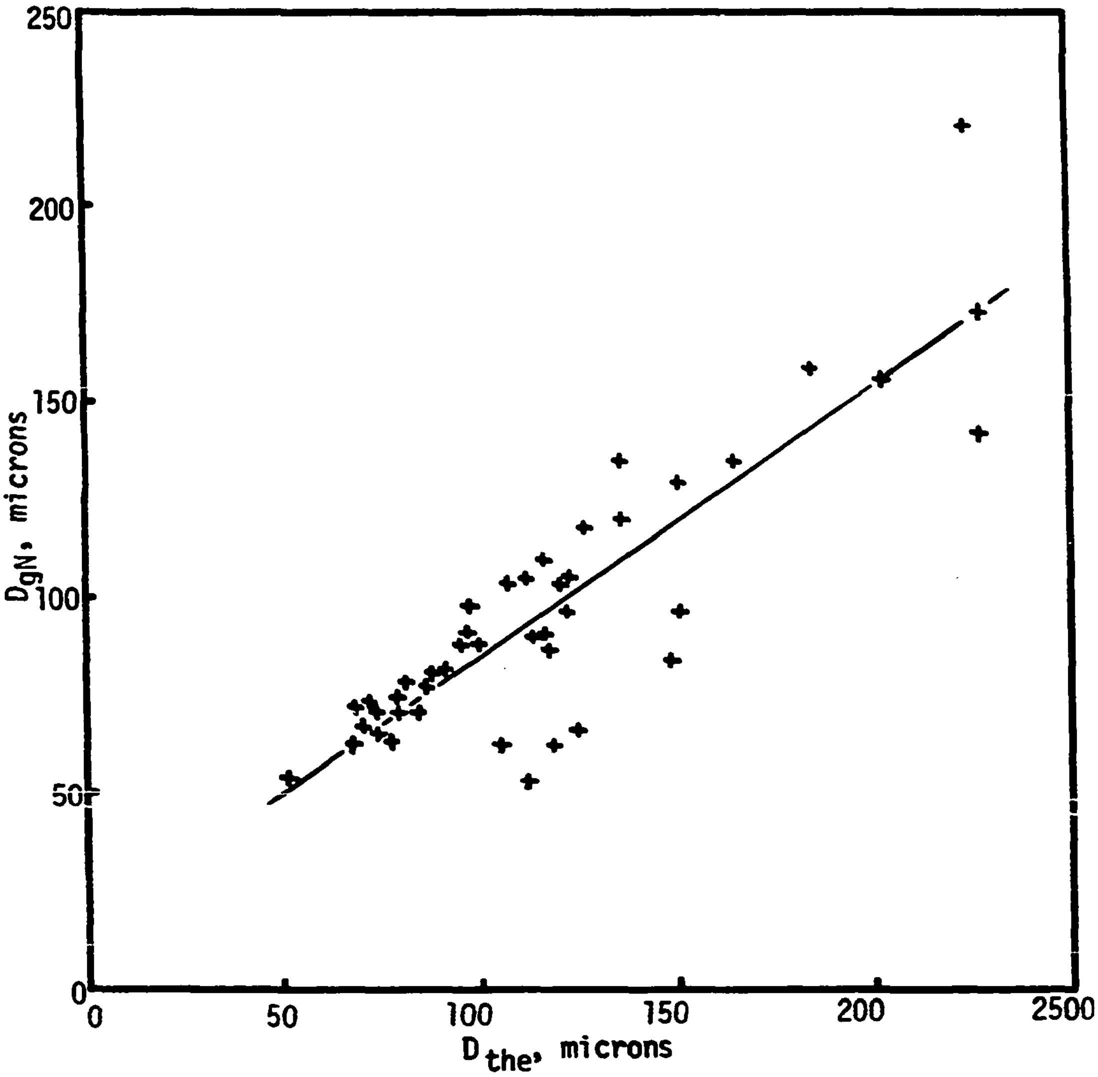

Figure 44. Correlation of D_{gN} and D_{the}

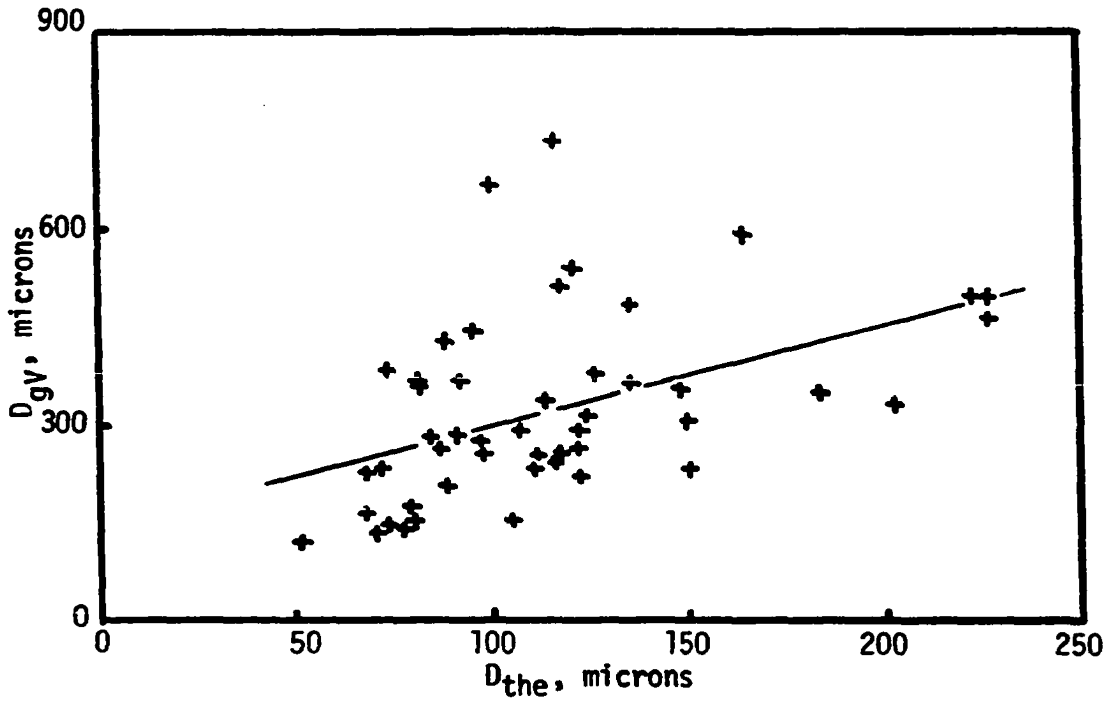

Figure 45. Correlation of D_{gV} and D_{the}

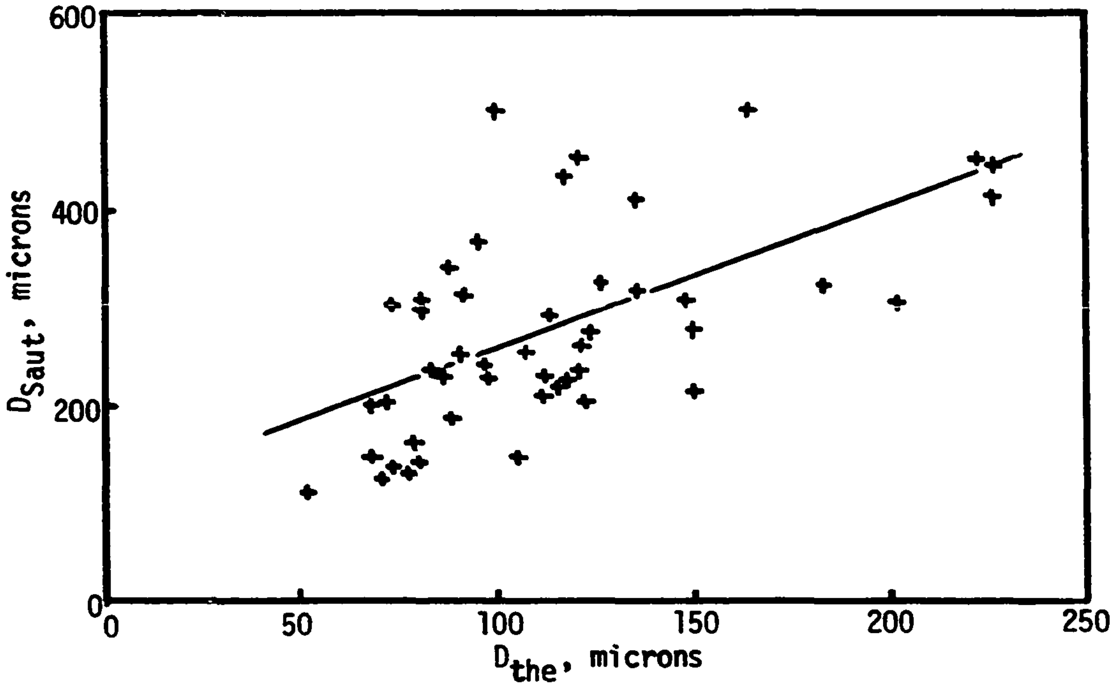

Figure 46. Correlation of D_{Saut} and D_{the}

Figures 49 and 50 show the relationship between standard deviations from classified data and that from the simplified measurements, for unweighted and volume weighted data, respectively. There is a good relationship with the unweighted distribution, but the statistics from the simplified measurements would be of little value in predicting the standard deviation of volume weighted classified data.

Figure 48 shows the ratio S_n/S_{the} as a function of the number of droplets in the sample. Clearly there is no significant effect.

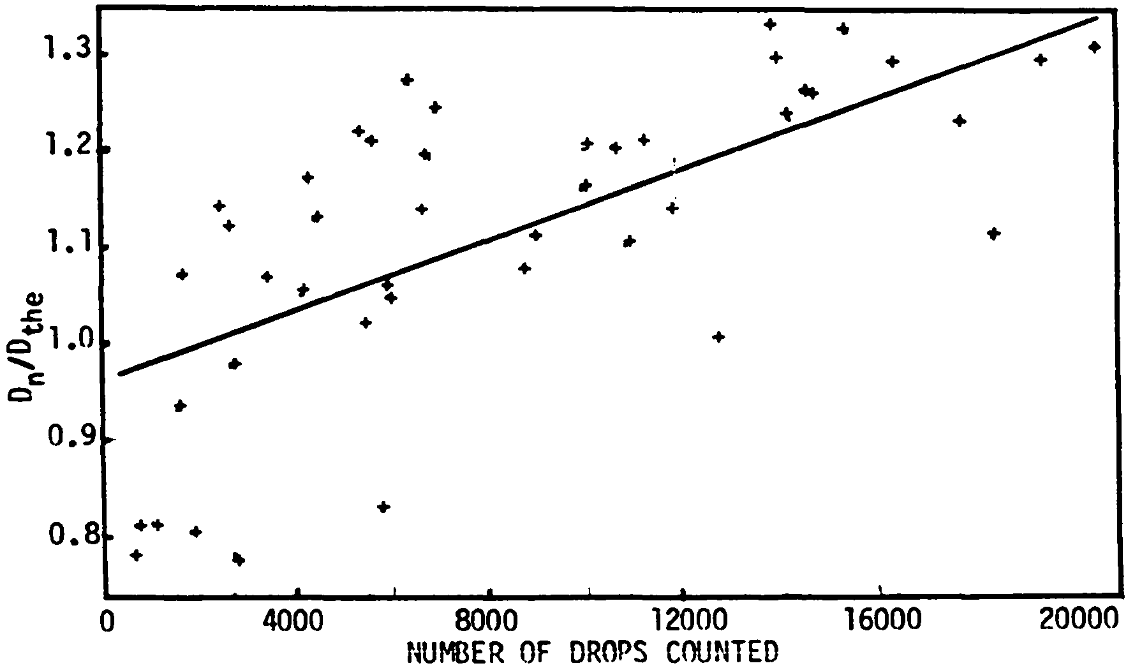

Figure 47. Prediction of classified count statistics from simplified measurement statistics, as affected by number of droplets counted on 25 frames

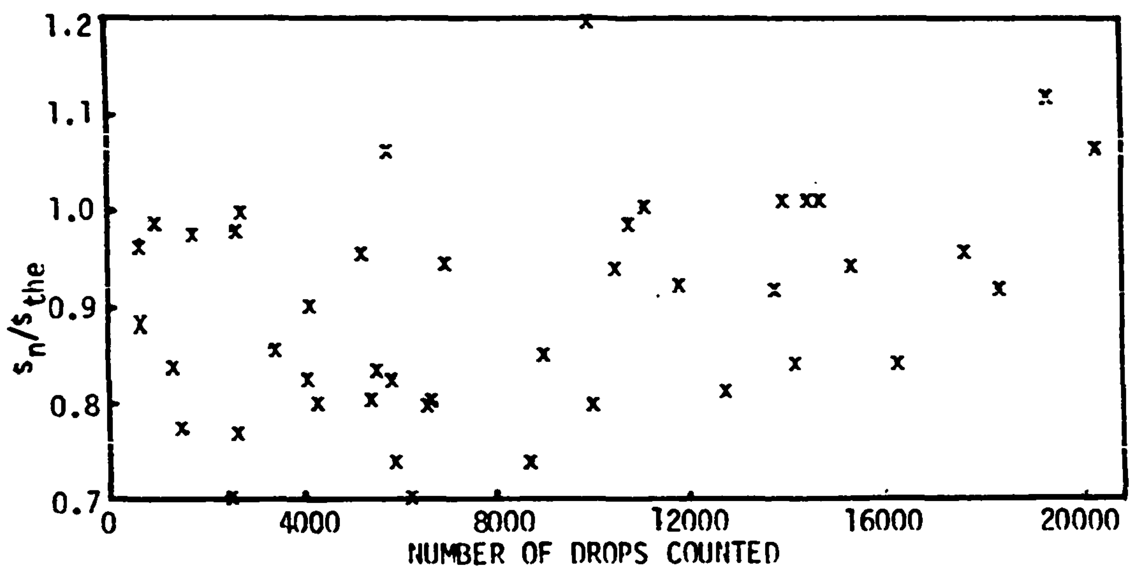

Figure 48. Prediction of classified count statistics from simplified measurement statistics, as affected by number of droplets counted on 25 frames

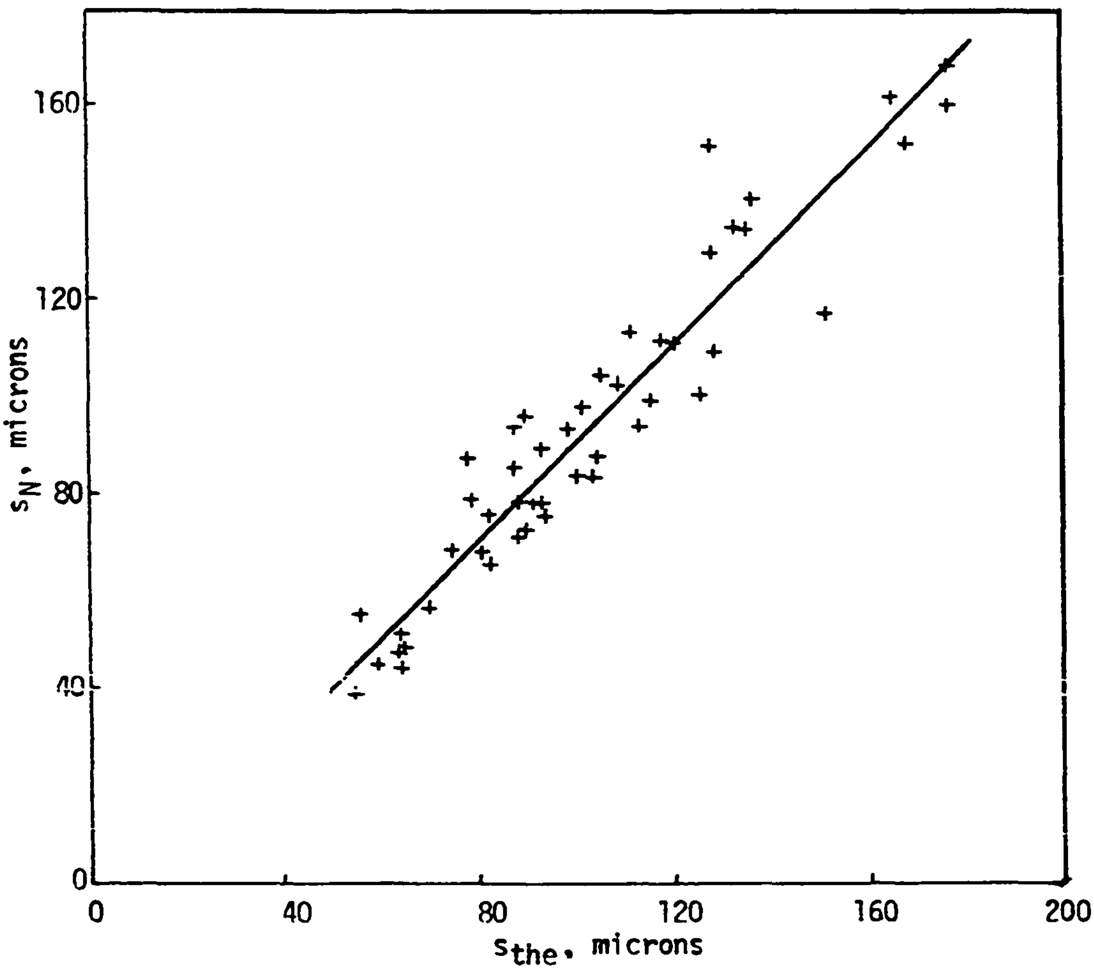

Figure 49. Correlation of s_N and s_{the}

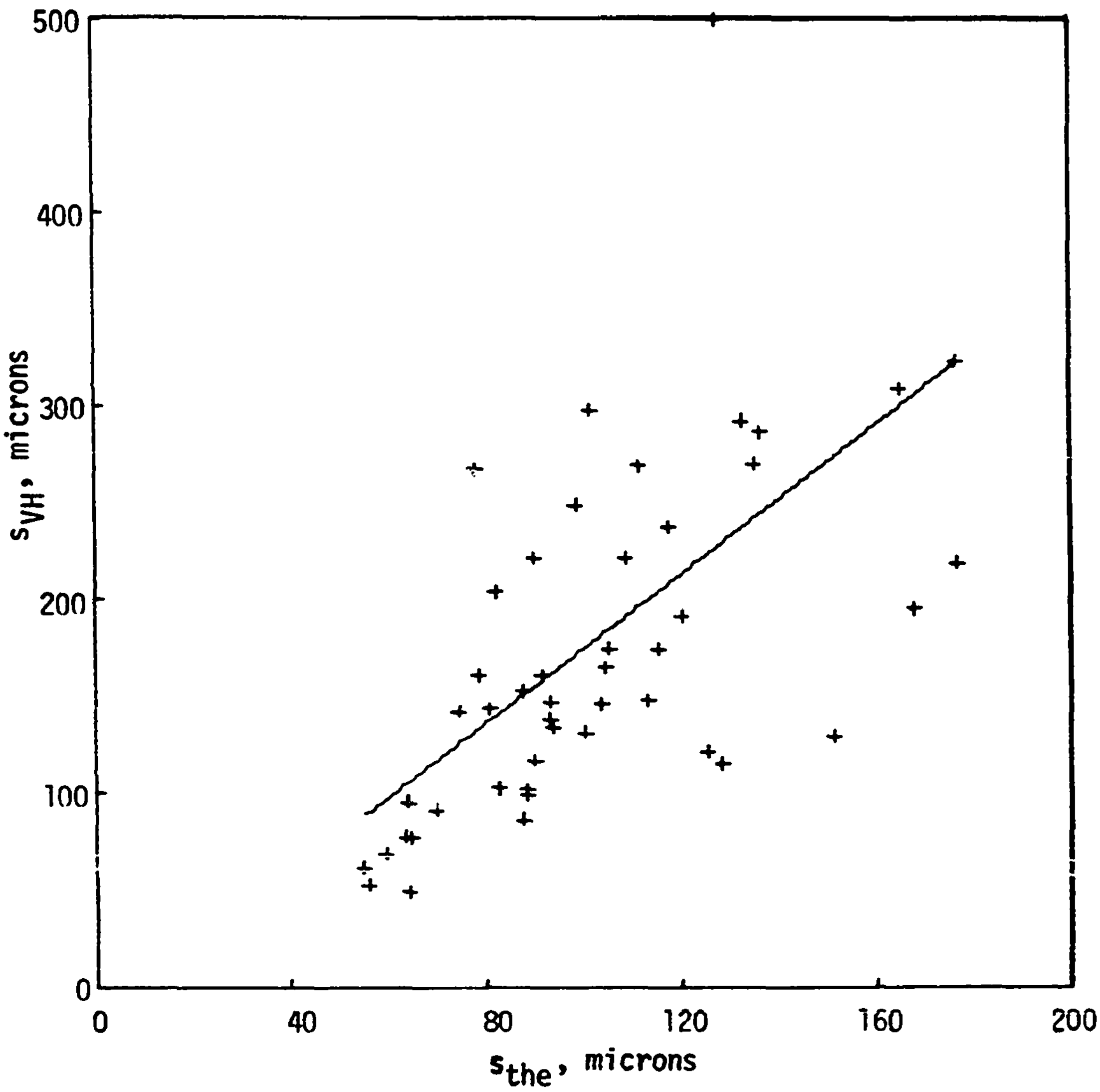

Figure 50. Correlation of s_{VH} and s_{the}

VI. DISCUSSION

A. Uniformity of Droplet Size

It has been commonly assumed that the dispersion of spray droplet size is approximately proportional to the mean of the distribution. This assumption was derived from frequent observations that drop sizes approximately followed a logarithmic normal distribution, and that the geometric standard deviation of such distributions did not vary greatly. Since it can be shown that the coefficient of variation of a log normal distribution is a function only of the geometric standard deviation of the distribution, if this does not vary much, then the coefficient of variation will also not vary much.

Although the droplet distributions in this study did not appear to fit log normal models very well, the data from the study did confirm the common assumption that the coefficient of variation does not vary widely in spray from a fan spray nozzle.

The lowest coefficient of variation computed from the data was 0.55. While it is nearly half of the largest value of this statistic computed, it still represents a highly nonuniform distribution. Thus, no spray measurements obtained from any of these tests of fan spray nozzles could be considered to be very uniform.

Furthermore, Equation 18a gives little basis for expectation that more uniform spray could be obtained from this type of nozzle by extending design and operating conditions in directions that reduce variation. This is because the exponents in the function in Equations 36 and 37 are so small. Only the fan angle, Θ, has an appreciable effect, but this cannot be increased very much beyond 1.8 radians without a radical change in the basic design of such nozzles. The effect of fan angle, however, does imply that hollow cone nozzles might produce more uniform spray than the fan spray nozzle, since the "fan angle" of the hollow cone might effectively be 2Π, or nearly 6 times greater than the fan angles used most commonly in the true fan nozzles. In view of this prospect, attempts to produce spray of much more uniform droplet size, e.g., with coefficient of variation less than 0.1, should be directed to development of new nozzles rather than expect that a change in the fluid properties or that some modification of conventional fan nozzles such as used in these experiments might yield these results.

B. Formulation of Results

Equations 34, 35, 36, and 37, and the data upon which they are based, cover a wider range of conditions than any previously known study of fan spray nozzles. There is appreciable scatter between the data and the fitted equations, however, and it is disappointing that the mean droplet statistics could not be represented by dimensionless variables.

It is not possible to compare these data with previous work in dimensionless form, except for the work by Dorman (1952). Even this is not directly comparable, as the mean used by Dorman was the Sauter mean diameter, which was not computed in the form of a dimensionless equation in this study. Comparison of the exponents of the power terms in Equations 20, 34, and 35 shows much similarity, however. Conversely, Dorman's equation is plotted on Figure 29. This shows that Dorman's equation is consistent with the data collected in this study, but would fit progressively more poorly at high values of p $A^{1/2}/\sigma$. Dorman's data exhibited considerably less scatter than the data in this study; however, he used only two liquids, used a narrower range of pressures, and used measurements of maximum drop size to compute the mean sizes reported, based upon a correlation which he established between maximum drop size observable and the Sauter mean diameter.

It is instructive to see how Equations 34 and 35 simplify at lower values of p $A^{1/2}/\sigma$. Dropping the first term in brackets yields, after some rearrangement:

$$D_N = (\sigma/p)^{0.33} A^{-0.05} \tag{38}$$

$$D_{VH} = (\sigma/p)^{0.4} \theta^{-0.33} A^{0.05} \tag{39}$$

These results predict a remarkably small influence of orifice size on the resulting droplet size. It follows that orifice size can be chosen to meet discharge requirements, after which the droplet size can be controlled by changing the pressure and the surface tension.

On the other hand, at sufficiently high values of p $A^{1/2}/\sigma$, if the second term in the brackets is dropped to estimate the right hand assymptote, one obtains $D_N \sim A^{0.25}$ and $D_{VH} \sim A^{0.12}$. Predicting drop size in this range, however, would involve extrapolating Equations 34 and 35 beyond the range of experimental data on which they are based.

C. Simplified Measurement Method

The ability to predict the arithmetic mean and standard deviation, shown in Chapter V, Section C, may be of considerable use in expediting droplet size measurement in situations where low droplet sample densities would otherwise reduce the value of automatic droplet sizing equipment. The apparent dependency of accuracy of size prediction on low sample densities will not affect the practical use of this method, as this condition is exactly the condition when the method is most likely to be used. Biological scientists who have become accustomed to use of volume weighted statistics, such as the mass median diameter, may be reluctant to use this simplified method, since it cannot be used to predict accurately any of the volume weighted statistics.

VII. SUMMARY

The objectives of this study were to obtain better measurements of central tendency and dispersion in drop sizes produced by agricultural fan spray nozzles, and to relate these measures to the operating conditions and nozzle design parameters. To attain these objectives, a series of controlled experiments were conducted in the laboratory.

The experiments were conducted at combinations of several levels of orifice size, liquid pressure, nominal fan angle, and liquid viscosity. An attempt was made to choose combinations of values of these conditions in such a way that orthogonal arrays of the dimensionless independent variables would result. Seven statistics indicating central tendency and four statistics indicating dispersion of the drop size distribution were computed for each experiment.

All mean drop sizes were influenced most strongly by nozzle size, operating pressure, and nominal fan angle. The manner in which these variables affected mean drop size also implied through dimensional analysis, that surface tension was equally as influential, although it did not vary greatly during these experiments. The small influence of $A^{1/2}\rho^{1/2}p^{1/2}/\mu$ implied that the spray liquid viscosity had less effect, at least to 17.8 centipoise, which was the highest value used.

In contrast, nominal fan angle, viscosity, surface tension, and pressure were more nearly equal in influencing dispersion measures computed from the data, such as coefficient of variation and geometric standard deviation.

A simplified method of estimating the mean and standard deviation of a sample of spray drops was derived. Statistics based on these simplified measurements were compared with statistics derived from the same spray droplet samples by counts in size classifications. The simplified statistics were found to be mostly related to statistics from classified data which had not been weighted. This relationship also appeared to be affected by the population density of the droplet samples from which the measurements were taken.

It was also found that the effect of orifice size could not be fully accounted for in the descriptive equations containing only the dimensionless variables $\overline{D}/A^{1/2}$, $p^{1/2}\ \rho^{1/2}\ A^{1/2}/\mu$ and $p\ A^{1/2}/\sigma$. The influence of other variables and biases in the collection and sampling procedure were suggested as possible reasons for this effect. Insufficient evidence was available to attribute this effect to any of the causes suggested. A considerable portion of variation in the drop size statistics which were computed was not accounted for by the descriptive equation derived to fit the experimental data. This fit was about the same as for one previously reported study on spray droplet size, and poorer than that shown by a second author.

VIII. CONCLUSIONS

The following conclusions were drawn from this study:

1. The coefficient of variation of spray droplet sizes produced by these nozzles varied from 0.56 to 1.09, and the influence of operating conditions and nozzle design parameters was best described by the expressions

$$s_N/D_N = 0.323\ (p\ A^{1/2}/\sigma)^{0.047}(p^{1/2}A^{1/2}\rho^{1/2}/\mu)^{0.06}\ \theta^{-0.136} \tag{36}$$

$$s_{VH}/D_{VH} = 0.062\ (p\ A^{1/2}/\sigma)^{0.124}(p^{1/2}A^{1/2}\rho^{1/2}/\mu)^{0.185}\theta^{-0.416} \tag{37}$$

where s_N is the standard deviation of the drop size distribution, D_N is the arithmetic mean, s_{VH} is the standard deviation of the volume weighted drop size distribution, D_{VH} is the mean of the volume weighted drop size distribution, p is the pressure at which the nozzle is operated, A is the cross sectional area of the nozzle orifice in square milimeters, σ is the liquid surface tension, ρ is the liquid density, μ is the liquid viscosity, and θ is the nominal fan angle for the nozzle.

2. The geometric standard deviation, resulting from logarithmic transformation of the distribution data, was not as predictable as ordinary coefficient of variation statistics.

3. The mean drop size produced by fan spray nozzles was described by the expressions

$$D_N/A^{1/2} = 0.109\ A^{-0.38}\ (1 + 13.77(p\ A^{1/2}/\sigma)^{-0.33}) \tag{34}$$

$$D_{VH}/A^{1/2} = 0.298\ \theta^{-0.33}\ A^{-0.25}\ (1+80.9(p\ A^{1/2}/\sigma)^{-0.4}) \tag{35}$$

The experimental data exhibited considerable deviation from this expression. The effect of orifice size could not be accounted for completely by dimensionless variables included in the hypothesis proposed at the beginning of the study.

4. A simplified method for computing mean and standard deviation of droplet diameters based upon the sum of droplet diameters and the sum of droplet cross sectional areas was useful in predicting statistics computed by classification and counting, if such statistics were not weighted by volume or some other function.
5. The poor relationship of parameters of a log normal distribution, based on log transformation of the experimental data, to other statistics computed directly implied that the drop size distribution data was not sufficiently well fitted by a log normal model that meaningful parameters for such a model could be estimated from the data.

IX. REFERENCES

Aitchison, J. and J. A. C. Brown. 1957. The lognormal distribution. Cambridge, England, Cambridge University Press.

Akesson, N. B. and W. E. Yates. 1961. Drift residue on alfalfa hay. California Agriculture 15(12): 4-7.

Argauer, R. J., H. C. Mason, C. Corley, A. H. Higgins, J. N. Sauls, and L. A. Liljedahl. 1968. Drift of water-diluted and undiluted formulations of malathion and azinphosmethyl applied by airplane. J. Econ. Entomology 61(4): 1005-1020.

Bengtsson, A. c1964. The influence of droplet size on the effect of weed killers. Royal Agricultural College Publication #7, Uppsula, Sweden. Translation available from Spraying Systems Co., Bellwood, Illinois.

Bowen, H. D., W. E. Splinter and W. M. Carleton. 1952. Theoretical implications of electrical fields on deposition of insecticides and fungicides on plant surfaces. J. Am. Soc. Agricultural Engineers 33: 347-350.

Burgoyne, W. E. and N. B. Akesson. 1968. Aircraft operations in the Colusa project. Down to Earth 24(2): 7-10.

Burt, E. C., D. B. Smith, and E. P. Lloyd. 1966. A rotary disc device for applying ultra-low-volume (undiluted) pesticides with ground equipment. J. Econ. Entomology 59(6): 1486-1489.

Carleton, W. M., L. A. Liljedahl, F. Irons, O. K. Heddon, and R. D. Brazee. 1960. The development of equipment in the application of agricultural chemicals. In The nature and fate of chemicals applied to soils, plants, and animals. U.S. Dept. Agr. ARS-20-9: 70-84.

Castleman, R. A. 1932. Mechanism of atomisation accompanying solid injection. N.A.C.A. Report 440. Washington, D.C., U.S. Government Printing Office.

Courshee, R. J. 1961. Avoidance of drift from airborne sprayers. Outlook on Agriculture 3(2): 76-80.

Davies, C. N. 1961. The respiratory system. Stanford Research Institute Journal 5(3): 123-125.

Davis, H. M. and K. R. Elliot. 1953. A rapid method for estimating aerial spray deposits. J. Econ. Entomology 46(5): 696-698.

Davis, J. M., W. E. Waters, D. A. Isler, R. Martineau, and J. W. Marsh. 1956. Experimental airplane spraying for spruce budworm control. Journal Economic Entomology 49(3): 338-341.

Doble, S. M. 1947. Design of centrifugal spray nozzles for outputs up to 1800 gallons per hour. Proc. Inst. Mech. Engineers 157: 103-111.

Dorman, R. G. 1952. The atomization of liquid in a flat spray. British Journal Applied Physics 3(6): 189-192.

Dombrowski, N. 1956. Photographic methods of analysis in chemical engineering. Trans. Inst. Chem. Engrs. 34(1): 35-43,62.

Douglas, G. 1968. A comparison of the "Vibrajet" nozzle and a fan jet for overall application of bipyridyl herbicides. Weeds Research 8(1): 14-27.

Duffie, J. A. and W. R. Marshall, Jr. 1953. Factors influencing the properties of spray dried materials. Chem. Eng. Prog. 49: 417-423, 480-486.

Ennis, W. B., Jr. and R. E. Williamson. 1963. Influence of droplet size on effectiveness of low-volume herbicidal sprays. Weeds 11(1): 67-72.

Fraser, R. P. and Paul Eisenklam. 1956. Liquid atomisation and the drop size of sprays. Trans. Inst. Chem. Engrs. 34(4): 294-319.

Fraser, R. P., P. Eisenklam, and N. Dombrowski. 1957. Liquid atomization in chemical engineering. British Chemical Engineering, Aug: 414-420; Sept.: 496-500; Oct.: 536-543; Nov.: 610-612.

Handbook of Chemistry and Physics. 1959. Cleveland, Ohio, Chemical Rubber Publishing Co.

Hartley, G. S. and R. T. Brunskill. 1958. Reflection of water drops from surfaces. In Danielli, J. F., K. G. A. Parkhurst, and A. C. Riddiford, editors. Surface phenomena in chemistry and biology. Pp. 214-223. New York, N.Y., Pergamon Press.

Hasson, D. and J. Mizrahi, J. 1961. The drop size of fan spray nozzles; measurements by the solidifying wax method compared with those obtained by other sizing techniques. Institute Chemical Engineers Transactions 39(6): 415-422.

Hedden, O. K. 1961. Spray drop sizes and size distribution in pesticide sprays. Am. Soc. Agricultural Engineers Transactions 4(2): 158, 159, and 163.

Herdan, G. 1960. Small particle statistics. New York, N.Y., Academic Press.

Himel, C. H. and A. D. Moore. 1967. Spruce budworm mortality as a function of aerial spray droplet size. Science 156: 1250-1251.

Horsfall, J. G. 1956. Principles of fungicidal action. Waltham, Massachusetts, Chronica Botanica Co.

Howard, G. A. and A. J. P. Martin. 1950. Hydrophobic support for reverse phase chromatography. Biochemistry J. 50: 532-536.

Ingebo, R. D. 1956. Drag coefficients for droplets and solid spheres in clouds accelerating in airstreams. N.A.C.A. Technical Note 3762.

Joyce, J. R. 1946. The wax method of spray particle size measurement. Shell Petroleum Co. Ltd., London, Technical Report No. LCT/7.

Kilpatrick, J. W. 1967. Performance specifications for ultra low volume aerial applications of insecticides for mosquito control. Pest Control 35(5): 80-84.

Kirch, J. H., R. H. Beatty, and R. J. Otten. 1958. Progress report on research with woody plants. Unpublished mimeographed paper presented at Northeastern Weed Control Conference, New York City, N.Y. Ambler, Pennsylvania, Amchem Products, Inc., Agricultural Chemicals Division.

Kleinman, G. D., I. West, and M. S. Augustine. 1960. Occupational disease in California attributed to pesticides and agricultural chemicals. Archives of Environmental Health 1(2): 118-124.

Longwell, J. P. 1943. Fuel oil atomization. Unpublished Ph.D. thesis. Cambridge, Massachusetts, Library, Massachusetts Institute of Technology.

Maksymiuk, B. 1964. A rapid method for estimating the atomization of oil base aerial sprays. J. Econ. Entomology 57(1): 16-19.

Mansberg, H. P. 1964. Photo-optical field measurements by flying spot scanners for biomedical applications. J. Soc. Photo Instr. Engr. 2: 83-88.

Marshall, W. R. 1954. Atomization and spray drying. Chem. Eng. Progress Monograph Series No. 2, vol. 50.

McNew, G. L. 1959. Landmarks during a century of progress in use of chemicals to control plant diseases. Plant pathology - problems and progress, 1908-1959. Madison, Wis., U. of Wisconsin Press.

Meyer, L. Donald. 1965. Simulation of rainfall for soil erosion research. Am. Soc. Agricultural Engineers Trans. 8(1): 63, 64, 65.

Middleton, M. R. and B. Lowe. 1967. Kaolin coated targets for the collection of spray deposits. Agr. Aviation 9(2): 46-48.

Mount, C. A., C. S. Lofgren, N. W. Pierce, and C. N. Husman. 1968. Ultra-low volume nonthermal aerosols for malathion and naled for adult mosquito control. Mosquito News 28(1): 99-103.

Mugele, R. A. and H. D. Evans. 1951. Droplet size distribution in sprays. Industrial and Engineering Chemistry 43: 1317-1324.

National Institute of Agricultural Engineering. 1958. Test of "Dorman" low pressure hollow cone spray nozzle. NIAE (Silsoe, England) Test Report 179.

Nelson, P. A. and W. F. Stevens. 1961. Size distribution of droplets from centrifugal spray nozzles. American Institute Chemical Engineers Journal 7(1): 80-86.

Ohnesorge, W. 1936. Die Bildung von Tropfen an Dusen und die Auflosung flussiger Strahlen. Z. Angew. Math. und Mech. 16: 355-358. Berlin. Original not inspected; cited in Marshall.

Ranz, W. E. 1955. On sprays and spraying. Pennsylvania State University Engineering Research Bulletin B-65.

Reeves, B. G., L. W. Wilkes, R. L. Ridgeway, and D. A. Lilquist. 1967. Design and evaluation of equipment for basal application of systemic insecticides to cotton plants. Am. Soc. Agricultural Engineers Transactions 10(2): 179-181.

Riley, H. W. 1909. A sprayograph. Am. Soc. Agricultural Engineers Transactions 3: 13-17.

Roth, L. O. 1966. Drift reduction through controlled atomization. Agrichemical West 1966: 7-8.

Rupe, J. H. 1949. A technique for the investigation of spray characteristics of constant flow nozzles. Proceedings, Fuel Spray Conference, University of Michigan. Original not available for inspection; cited in Tate, R. W. and W. R. Marshall, Jr. 1953.

Scheubel, F. N. 1927. Uber die Serstaubung in Vergasern. Jahrbuch Wiss. Ges. Luftfahrt. Berlin. Translated in N.A.C.A. Memo. 644, 1931.

Schmidt, P. 1967. Zerteilen von Flussigkeiten in gleich grosse Tropfen. Chemie-Ingenieur-Technik 39: 375-379.

Seymour, K. G. and B. C. Byrd. 1964. Particulate sprays for reducing drift from herbicide applications. Northeastern Weed Control Conference Proceedings 18: 399-408.

Skoog, F. E., F. T. Cowan, and K. Messenger. 1965. Ultra low volume aerial spraying of dieldrin and malathion for rangeland grasshopper control. J. Econ. Entomology 58(3): 559-565.

Stanton, B. F. and B. A. Dominick, Jr. 1963. Cost of producing apples for fresh market. Cornell University Agricultural Economics Extension Mimeo 256.

Strickler, P. E. and W. C. Hinson. 1962. Extent of spraying and dusting on farms, 1958 - with comparisons. U.S. Dept. of Agr. Economics Research Service Statistical Bulletin 314.

Sweet, G. 1964. High frequency oscillography with electrostatically deflected ink jets. Stanford Electronics Laboratories Technical Report 1722-1.

Tate, R. W. and L. F. Janssen. 1966. Droplet size data for agricultural spray nozzles. Am. Soc. Agricultural Engineers Transactions 9(3): 303-305, 308.

Tate, R. W. and W. R. Marshall, Jr. 1953. Atomization by centrifugal pressure nozzles. Chem. Eng. Progress 49(4): 169-174 and 49(5): 226-234.

Turner, G. M. and R. W. Moulton. 1953. Drop size distribution from spray nozzles. Chem. Engr. Prog. 49(4): 185-190.

Walton, W. H. and W. E. Prewett. 1949. The production of sprays and mists of uniform drop size by means of spinning disc type sprayers. Proc. Physical Society B(62) Part VI, No. 354B: 342-350.

Wilson, J. D., O. K. Hedden, and J. P. Sleesman. 1963. Spray droplet size as related to disease and insect control on row crops. Ohio Agricultural Experiment Station Research Bulletin 945.

Yeomans, A. H., E. A. Rogers, and W. H. Ball. 1949. Deposition of aerosol particles. Journal Economic Entomology 42(4): 591-596.

X. NOTATION USED

It will be noted that the letters σ and μ are both used to denote two entirely different quantities, a practice which is usually avoided. However, the usages shown are well established in the fields of statistics and fluid mechanics. Since the different usages appear in entirely separate equations, we do not believe it should be misleading.

A = cross sectional area of orifice.

A_s = cross sectional area of droplet images on film.

c = general term for coefficient of variation.

D = droplet diameter.

$\overline{D}$ = general term for droplet mean, such as D_n, D_{VH}, D_{VME}, D_{gN}, or D_{gV}, listed below.

D_{gN} = geometric number mean diameter, defined in Equation 6.

D_{gV} = geometric volume mean diameter, defined in Equation 7.

D_{mm} = mass, or volume, median diameter, defined as the size of droplet such that half of the volume of spray is contained in droplets which are smaller than this size.

D_n = number mean diameter, defined in Equation 2.

D_{VME} = volume mean diameter attributed to Mugele and Evans (1951), defined in Equation 3.

D_{VH} = volume mean diameter attributed to Herdan (1960), defined in Equation 5.

D_{Saut} = Sauter mean diameter, defined in Equation 8.

D_{the} = number mean diameter computed from simplified measurements, defined in Equation 26.

d = orifice diameter.

D_m = maximum droplet size in a droplet population.

f = frequency function notation for frequency of droplet size sampled over a unit time

f' = function notation for frequency of droplet size sampled over a unit of space.

i = index value for discrete counts.

L = sum of droplet diameters in a sample.

n_{ch} = number of chords intercepted.

n_p = number of pulses in intercepted chords.

p = pressure drop of liquid through nozzle orifice.

Q = volumetric discharge of nozzle.

R = Reynolds number, $vd\rho/\mu$.

s = standard deviation.

s_N = number standard deviation, defined in Equation 12.

s_{VH} = volume standard deviation, defined in Equation 13.

s_{gN} = geometric standard deviation of the number distribution, defined in Equation 14.

s_{gV} = geometric standard deviation of the volume distribution, defined in Equation 15.

W = Weber number, $v^2d\rho/\sigma$.

β = cone half angle of hollow cone nozzle, radians.

δ_p = spacing of clock pulses on raster line.

δ_r = spacing of scan lines in cathode ray tube raster.

μ = parametric mean of a population distribution.

μ = absolute viscosity.

Π = any valid dimensionless product of variables.

σ = surface tension.

σ^2 = variance of a population distribution.

ρ = density.

θ = nominal angle of fan spray nozzle

S_{sr} = square root standard deviation.

v = liquid eflux velocity from orifice.

χ^2 = goodness of fit statistic.

XI. ACKNOWLEDGEMENTS

The author would like to express his appreciation to:

The Agricultural Research Service, United States Department of Agriculture for providing the facilities and support for this study.

Dr. W. F. Buchele for serving as major professor and for guidance in this study, particularly for provocative discussion during the planning of the study.

Mr. W. G. Lovely of the United States Department of Agriculture for helpful guidance and support in conducting this study.

Dr. W. M. Carleton of the United States Department of Agriculture for encouragement and special assignments to conduct the study.

Delavan Manufacturing Company, West Des Moines, Iowa, and Spraying Systems Company, Bellwood, Illinois, for supplying specimens of nozzles used in the study.

His wife, Joan, and children, for deferring many domestic amenities to permit completion of this study.

XII. APPENDIX A. COMPUTER PROGRAM FOR DATA REDUCTION

```
C     LILJEDAHL    SPRAY DROP SIZE ANALYSIS
C
C     THIS PROGRAM IS DESIGNED TO COMPUTE VARIOUS STATISTICS FROM
C     SPRAY DROP SIZE MEASUREMENTS, PARTICULARLY, MEASUREMENTS
C     RECORDED ON PUNCHED CARDS FROM THE WOOSTER PARTICLE COUNTER.
C     THE OUTPUT CONSISTS OF A SELF EXPLANATORY LISTING (FORMATS
C     (101 - 104), PLUS CARDS SUITABLE FOR MACHINE PLOTTING OR FURTHER
C     COMPUTATION.
C
C     INPUT PARAMETERS ARE --  N = TEST IDENTIFICATION NUMBER,
C       FMAG = DROP TO FILM SPOT MAGNIFICATION, ICHEK = A DUMMY VARIABLE
C       USED FOR AN IDENTITY CHECK TO DETERMINE IF DATA CARDS MIGHT
C       BE OUT OF ORDER AND IF NEW SIZE CLASSIFICATIONS APPLY TO THE
C       NEXT DATA SET, AND K(I) = SIZE CLASSIFICATIONS SET ON THE
C       WOOSTER COUNTER WHEN MAKING COUNTS.
C
C     INPUT DATA CONSISTS OF --NCUMR(I) =NUMBER OF SPOTS LARGER THAN
C       K(I) COUNTED BY THE WOOSTER COUNTER.
C
C     OUTPUT DATA CONSISTS OF -- A(I) = CENTER OF DROP SIZE CLASS,
C       K(I) = LOWER LIMIT OF DROP SIZE CLASS, M(I) = UPPER LIMIT OF
C       DROP SIZE CLASS, NO(I) = NUMBER OF DROPS IN CLASS, PN(I)  =
C       PROPORTION OF NUMBER OF DROPS IN CLASS, PV(I) = PROPORTION
C       OF SPRAY VOLUME IN CLASS, SPN(I) = INTEGRAL OF PN(I), AND
C       SPN(I) = INTEGRAL OF PV(I).
```

```
C
C     OUTPUT STATISTICS CONSIST OF -- DNTHE =MEAN DROPLET DIAMETER
C       COMPUTED FROM INTERCEPT MEASUREMENTS, SDTHE = STANDARD
C       DEVIATION OF  DROPLET SIZE COMPUTED FROM INTERCEPT MEASUREMENTS,
C       DMN =  MEAN DIAMETER COMPUTED FROM COUNTS, SDN = STANDARD
C        DEVIATION OF DROP SIZE COMPUTED FROM COUNTS, VMD = VOLUME MEAN
C        DIAMETER, VLD = VOLUME WEIGHTED MEAN DIAMETER, SDV = VOLUME
C        WEIGHTED STANDARD DEVIATION, DMM = MASS MEDIAM DIAMETER.
C        XM = GEOMETRIC MEAN DIAMETER, XSD = GEOMETRIC STANDARD
C        DEVIATION, ZM = GEOMETRIC VOLUME WEIGHTED MEAN DIAMETER.
C        ZSD = GEOMETRIC VOLUME WEIGHTED STANDARD DEVIATION, AND
C        DSAUT = SAUTER MEAN DIAMETER.
C
      DIMENSION  M(42),ND(42),PV(42), NCUM(42),K(43),SPV(42)
      DIMENSION  X(42),PN(42), V(42),NCUMR(42),A(42),SPN(42)
C
C
C      FOR EACH TEST WE READ IN THE TEST NUMBER, THE NUMBER OF FRAMES
C      COUNTED  (TO CONTROL CARD READING), AND A DUMMY VARIABLE CALLED
C      ICHEK WHICH WE  SET EQUAL TO 1111 IF NEW CLASS SIZES ARE TO BE
C      USED, 5555 IF THE CLASS SIZES FROM THE PREVIOUS TEST ARE VALID
C      FOR THIS ONE, AND 9999 AT THE END OF DATA.  ANY OTHER NUMBER WILL
C      CAUSE THE PROGRAM TO BRANCH TO PRINT A MESSAGE "CARDS OUT OF
C      ORDER" AND STOP.  THE SPOT MAGNIFICATION IS ALSO READ IN.
C
    1 READ(5,98) N, NREP,ICHEK,FMAG
      IF (ICHEK -5555) 2,6,997
    2 IF(ICHEK - 1111) 998,3,998
    3 READ(5,99) NCLAS,(K(I),I=1,43)
```

```
      DO 4 I= 1,42
    4 K(I)=(FLOAT(K(I)))/FMAG
      DO 5 I = 1,42
      M(I) = K(I+1)
    5 A(I) = (FLOAT(K(I) + K(I+1)))/2.0
    6 DO 7 I = 1,42
      SPN(I)=0
      SPV(I)=0
      NCUMR(I) = 0
    7 NCUM(I) = 0
      IK = -1
      DNTHE = 0
      SOTHE = 0
      L = 0
      NA = 0
C
C      READ IN DATA FROM WOOSTER COUNTER, AND SUM DATA FROM ALL FRAMES.
C
      DO 9 J =1, NREP
      READ(5,100) NAR,LR,(NCUMR(I),I=1,NCLAS)
      DO 8 I =1,NCLAS
    8 NCUM(I) = NCUM(I) + NCUMR(I)
      NA = NA + NAR
    9 L = L + LR
      DO 12 I = 1, NCLAS
      NO(I) = NCUM(I) - NCUM(I+1)
      IF(NO(I))10,10,11
```

```
 10 NC(I)=0
 11 IF (NCUM(I))13,13,12
 12 CONTINUE
 13 NMAX = I-1
C
C       COMPUTE MEAN AND STD DEV FROM INTERCEPT DATA.
C
      ON = NCUM(1)
      AN = NA
      AL = L
      AR = 197.8*AN/(FMAG*FMAG)
      SUML =  19.78*AL/FMAG
      ONTHE =SUML/ON
      SSTHE = (4.*AR)/(ON*3.1415926)-(SUML*SUML)/(ON*ON)
      SDTHE = SQRT(SSTHE)
C
C       COMPUTE NUMBER AND VOLUME DISTRIBUTION, AREA AND VOLUME TOTALS,
C       AND THE SAUTER MEAN AND VOLUME MEAN DIAMETER (MUEGELE-EVANS).
C
      AT = 0
      VT = 0
      XM = 0
      ZM = 0
      DMN = 0
      VLD = 0
      SSN = 0
      SSV = 0
      SSX = 0
      SSZ = 0
```

```
      DO 14 I = 1, NMAX
      PN(I)=NO(I)/ON
      AT = AT + NO(I)*A(I)*A(I)
      V(I) = NO(I)*A(I)*A(I)*A(I)
   14 VT =VT +V(I)
      VMD = (VT/ON)**0.333333
      DO 15 I = 1, NMAX
   15 PV(I) =V(I)/VT
C
C      INTEGRATE THE DISTRIBUTIONS ABOVE AND FIND MASS MEDIAN DIAMETER.
C
      SPN(1) = PN(1)
      SPV(1) = PV(1)
      DO 20 I = 2, NMAX
      SPN(I) = SPN(I-1) + PN(I)
      SPV(I) = SPV(I-1) + PV(I)
      IF (IK) 16,16,20
   16 IF (SPV(I) - 0.5)20,17,18
   17 DMM = M(I)
      GO TO 19
   18 DMM = M(I-1)+(0.5-SPV(I-1))*(M(I)-M(I-1))/(SPV(I)-SPV(I-1))
   19 IK = IK + 2
   20 CONTINUE
      WRITE(6,101) N
C
C      COMPUTE MEAN AND STD DEV OF THE NUMBER AND VOLUME DISTRIBUTIONS.
C
```

```
      DO 21 I = 1, NMAX
      SSN = SSN  + PN(I) *A(I) *A(I)
      DMN=DMN + PN(I)*A(I)
      SSV = SSV  + PV(I) *A(I) *A(I)
      VLD = VLD  + PV(I)*A(I)
C
C
C      PUNCH CARDS ON DISTRIBUTION DATA.
C
      WRITE(4,108) N,A(I),NO(I),PN(I),PV(I),SPN(I),SPV(I)
C
C      PRINT OUT DISTRIBUTION DATA.
C
   21 WRITE(6,103) K(I),M(I),NO(I),PN(I),PV(I),SPN(I),SPV(I)
C
C      TAKE LOGARITHMS OF CLASS MIDPOINTS AND COMPUTE GEOMETRIC MEAN
C      AND STANDARD DEVIATION OF BOTH NUMBER AND VOLUME DISTRIBUTIONS.
C
      DO 22 I = 1, NMAX
      X(I) = ALOG (A(I))
      ZM = ZM + PV(I)*X(I)
      XM = XM + PN(I)*X(I)
      SSZ = SSZ + PV(I) * X(I)*X(I)
   22 SSX = SSX + PN(I) * X(I)*X(I)
      SSX = SSX - XM*XM
      SSZ = SSZ - ZM*ZM
      XSD = SQRT (SSX)
      ZSD = SQRT (SSZ)
      XM  =EXP (XM)
```

```
      ZM   =EXP (ZM)
      SSN = SSN - (DMN)*(DMN)
      SDN = SQRT (SSN)
      SSV= SSV - (VLD)*(VLD)
      SDV   = SQRT (SSV)
      DSAUT = VT/AT
C
C      PRINT OUT DISTRIBUTION STATISTICS.
C
      WRITE(6,104)N,NCUM(1),DNTHE,SDTHE,DMN,SDN,VMD,VLD,SDV,DMM,XM,XSD,
     C ZM,ZSD,DSAUT
C
C      PUNCH CARDS ON DISTRIBUTION STATISTICS.
C
      WRITE(4,109)N,DNTHE,SDTHE,DMN,SDN,VMD,VLD,SDV,DMM,XM,XSD,
     C ZM,ZSD,DSAUT
C
C      END OF COMPUTATIONS FOR ONE EXPERIMENT. LOOP BACK TO DATA LEADER.
C
      GO TO 1
  997 IF(ICHEK - 9999) 998,999,998
  998 WRITE (6, 110 )
  999 STOP
   98 FORMAT (I2,3X,I2,13X,I4,5X,F5.2)
   99 FORMAT (5X, I2, 1X,18I4/(20I4))
  100 FORMAT (4X,I7,I5 ,16I4/(4X,I7,I5,16I4))
  101 FORMAT (1H1,15X,'TEST NUMBER',I4,T32,'  -- DISTRIBUTION DATA',//
```

```
   C  T13,'DROP    ',T21,'NUMBER ',T29,'PORTION',
   C            T38,'PORTION', T47,'SUM OF ',T56,'SUM OF ',/
   C  T13,'SIZE',T21,'OF',T29,'OF',T38,'OF',T47,'PORTION',T56,'VOLUME',
   C  /T13,'CLASS, ',T21,'DROPS  ',T29,'DROPS  ',
   C            T38,'VOLUME ', T47,'IN AND ',T56,'IN AND ',/
   C  T13,'MICRONS',T21,'IN',T29,'IN',T38,'IN',T47,'BELOW',T56,'BELOW',
   C  /T21,'CLASS',T29,'CLASS',T38,'CLASS',T47,'CLASS',T56,'CLASS',/)
103 FORMAT(10X,I4,I5,I5,4X,F6.4,3X,F6.4,3X,F6.4,3X,F6.4)
104 FORMAT (1H1/////18X,11HTEST NUMBER,I3,1H,,I7,13H DROP SAMPLE.,
   C        /18X,32HCOMPUTED DISTRIBUTION STATISTICS,//
   C    /16X,31HMEAN DIAMETER FROM INTERCEPTS =,F6.1,8H MICRONS/
   C    /16X,36HSTANDARD DEVIATION FROM INTERCEPTS =,F6.1,8H MICRONS/
   C    /16X,27HMEAN DIAMETER FROM COUNTS =, F6.1,8H MICRONS/
   C    /16X,32HSTANDARD DEVIATION FROM COUNTS =, F6.1,8H MICRONS/
   C    /16X,28HVOLUME MEAN (MUGELE-EVANS) =, F6.1,8H MICRONS/
   C    /16X,22HVOLUME MEAN (HERDAN) =, F6.1,8H MICRONS/
   C    /16X,27HVOLUME STANDARD DEVIATION =, F6.1, 8H MICRONS/
   C    /16X,22HMASS MEDIAN DIAMETER =, F6.1, 8H MICRONS/
   C    /16X,32HGEOMETRIC NUMBER MEAN DIAMETER =,F6.1,8H MICRONS/
   C    /16X,28HGEOMETRIC NUMBER STD. DEV. =,F6.4/
   C    /16X,32HGEOMETRIC VOLUME MEAN DIAMETER =,F6.1,8H MICRONS/
   C    /16X,28HGEOMETRIC VOLUME STD. DEV. =,F6.4/
   C    /16X,22HSAUTER MEAN DIAMETER =, F6.1,8H MICRONS)
108 FORMAT (10HDIST DATA ,I2,1X,F5.?,1X,I5,1X,F6.3,1X,F6.3,
   C  1X,F6.3,1X,F6.3)
109 FORMAT(I2,F6.1,F6.1,F6.1,F6.1,F6.1,F6.1,F6.1,F6.1,F6.1,F5.3,F6.1,
   C  F6.3,F5.1)
110 FORMAT (1H1,/////////, 24HINPUT CARDS OUT OF ORDER   )
    END
```

XIII. APPENDIX B. SYNTHETIC DISTRIBUTION FOR PROGRAM TESTING

In order to debug the data reduction program and test if for accuracy, a synthetic distribution was made up and reduced by hand calculation to permit comparison with results from the computer. The distribution used was as follows:

Drop size, microns	Number
50	1
150	1
250	1
350	1
450	1

This could be a sample from a uniform distribution, from which the actual parameters could be computed. In this case, μ = 2504 and σ = 141μ. Likewise the parameters could be computed for such a distribution if it were volume weighted, in which case one would have $v(D) = \frac{4 \times 10^{-8}}{625} D^3$, for which μ_v = 400μ and σ_v = 81.64μ.

The output from the data reduction program is given on the following page. In all cases the computer output agreed with hand calculated values within the limits of calculation precision used. The discrepancy between the computed values and parameters referred to above is caused by classification effects.

TEST NUMBER 0 -- DISTRIBUTION DATA

DROP SIZE CLASS. MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	100	1	0.2000	0.0008	0.2000	0.0008
100	200	1	0.2000	0.0220	0.4000	0.0229
200	300	1	0.2000	0.1020	0.6000	0.1249
300	400	1	0.2000	0.2800	0.8000	0.4049
400	500	1	0.2000	0.5951	1.0000	1.0000

TEST NUMBER 0, 5 DROP SAMPLE.
COMPUTED DISTRIBUTION STATISTICS

MEAN DIAMETER FROM INTERCEPTS = 249.2 MICRONS

STANDARD DEVIATION FROM INTERCEPTS = 142.8 MICRONS

MEAN DIAMETER FROM COUNTS = 250.0 MICRONS

STANDARD DEVIATION FROM COUNTS = 141.4 MICRONS

VOLUME MEAN (MUGELE-EVANS) = 312.9 MICRONS

VOLUME MEAN (HERDAN) = 394.7 MICRONS

VOLUME STANDARD DEVIATION = 77.0 MICRONS

MASS MEDIAN DIAMETER = 416.0 MICRONS

GEOMETRIC NUMBER MEAN DIAMETER = 196.8 MICRONS

GEOMETRIC NUMBER STD. DEV. =0.7777

GEOMETRIC VOLUME MEAN DIAMETER = 384.9 MICRONS

GEOMETRIC VOLUME STD. DEV. =0.2430

SAUTER MEAN DIAMETER = 371.2 MICRONS

XIV. APPENDIX C. EXPERIMENTAL DROPLET SIZE DISTRIBUTION DATA

TEST NUMBER 4 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	416	0.0462	0.0000	0.0462	0.0000
20	30	797	0.0884	0.0004	0.1346	0.0004
30	40	719	0.0798	0.0009	0.2144	0.0013
40	50	686	0.0761	0.0018	0.2905	0.0032
50	60	626	0.0695	0.0031	0.3599	0.0062
60	70	549	0.0609	0.0044	0.4208	0.0107
70	80	538	0.0597	0.0067	0.4805	0.0174
80	90	947	0.1051	0.0171	0.5856	0.0345
90	100	410	0.0455	0.0104	0.6311	0.0449
100	120	660	0.0732	0.0259	0.7043	0.0708
120	140	536	0.0595	0.0347	0.7638	0.1055
140	160	455	0.0505	0.0453	0.8143	0.1508
160	180	336	0.0373	0.0487	0.8515	0.1995
180	200	433	0.0480	0.0876	0.8996	0.2870
200	230	301	0.0334	0.0882	0.9330	0.3752
230	260	201	0.0223	0.0872	0.9553	0.4624
260	290	125	0.0139	0.0767	0.9692	0.5391
290	320	108	0.0120	0.0904	0.9811	0.6294
320	360	71	0.0079	0.0823	0.9890	0.7117
360	400	54	0.0060	0.0874	0.9950	0.7991
400	460	19	0.0021	0.0445	0.9971	0.8436
460	520	19	0.0021	0.0659	0.9992	0.9095
520	580	6	0.0007	0.0294	0.9999	0.9390
580	640	0	0.0	0.0	0.9999	0.9390
640	720	1	0.0001	0.0093	1.0000	0.9482
720	800	4	0.0004	0.0518	1.0004	1.0000

TEST NUMBER 5 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	546	0.0387	0.0000	0.0387	0.0000
20	30	1022	0.0724	0.0001	0.1111	0.0001
30	40	1068	0.0757	0.0003	0.1868	0.0004
40	50	962	0.0682	0.0006	0.2550	0.0011
50	60	873	0.0619	0.0010	0.3169	0.0021
60	70	875	0.0620	0.0017	0.3789	0.0038
70	80	779	0.0552	0.0023	0.4341	0.0060
80	90	1442	0.1022	0.0062	0.5363	0.0122
90	100	661	0.0468	0.0040	0.5831	0.0162
100	120	1101	0.0780	0.0102	0.6612	0.0264
120	140	927	0.0657	0.0142	0.7269	0.0407
140	160	638	0.0452	0.0150	0.7721	0.0557
160	180	479	0.0339	0.0164	0.8060	0.0722
180	200	581	0.0412	0.0278	0.8472	0.1000
200	230	484	0.0343	0.0336	0.8815	0.1336
230	260	335	0.0237	0.0344	0.9052	0.1680
260	290	251	0.0178	0.0365	0.9230	0.2045
290	320	269	0.0191	0.0533	0.9421	0.2578
320	360	150	0.0106	0.0412	0.9527	0.2990
360	400	261	0.0185	0.1001	0.9712	0.3991
400	460	138	0.0098	0.0767	0.9810	0.4757
460	520	120	0.0085	0.0986	0.9895	0.5744
520	580	54	0.0038	0.0628	0.9933	0.6372
580	640	60	0.0043	0.0952	0.9976	0.7323
640	720	33	0.0023	0.0725	0.9999	0.8048
720	800	23	0.0016	0.0705	1.0016	0.8754
800	920	12	0.0009	0.0533	1.0024	0.9287
920	1040	2	0.0001	0.0132	1.0025	0.9418
1040	1160	3	0.0002	0.0279	1.0028	0.9697
1160	1280	1	0.0001	0.0127	1.0028	0.9824
1280	1440	1	0.0001	0.0176	1.0029	1.0000

TEST NUMBER 6 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	12	0.0021	0.0000	0.0021	0.0000
10	20	184	0.0328	0.0000	0.0349	0.0000
20	30	195	0.0347	0.0001	0.0696	0.0001
30	40	244	0.0435	0.0003	0.1131	0.0004
40	50	240	0.0428	0.0006	0.1559	0.0010
50	60	256	0.0456	0.0012	0.2015	0.0022
60	70	266	0.0474	0.0021	0.2488	0.0043
70	80	226	0.0403	0.0027	0.2891	0.0069
80	90	538	0.0958	0.0093	0.3849	0.0162
90	100	306	0.0545	0.0074	0.4394	0.0236
100	120	512	0.0912	0.0192	0.5306	0.0428
120	140	443	0.0789	0.0274	0.6095	0.0702
140	160	487	0.0867	0.0462	0.6963	0.1164
160	180	357	0.0636	0.0493	0.7599	0.1658
180	200	405	0.0721	0.0782	0.8320	0.2439
200	230	296	0.0527	0.0828	0.8848	0.3267
230	260	224	0.0399	0.0927	0.9247	0.4194
260	290	129	0.0230	0.0755	0.9476	0.4949
290	320	119	0.0212	0.0950	0.9688	0.5899
320	360	54	0.0096	0.0597	0.9784	0.6496
360	400	48	0.0086	0.0741	0.9870	0.7237
400	460	31	0.0055	0.0693	0.9925	0.7930
460	520	21	0.0037	0.0695	0.9963	0.8625
520	580	12	0.0021	0.0562	0.9984	0.9187
580	640	3	0.0005	0.0192	0.9989	0.9379
640	720	5	0.0009	0.0442	0.9998	0.9821
720	800	0	0.0	0.0	0.9998	0.9821
800	920	1	0.0002	0.0179	1.0000	1.0000

TEST NUMBER 9 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	361	0.0305	0.0000	0.0305	0.0000
20	30	630	0.0532	0.0000	0.0837	0.0000
30	40	631	0.0533	0.0001	0.1370	0.0002
40	50	621	0.0525	0.0003	0.1895	0.0004
50	60	599	0.0506	0.0004	0.2401	0.0009
60	70	664	0.0561	0.0008	0.2962	0.0017
70	80	648	0.0547	0.0012	0.3509	0.0029
80	90	1147	0.0969	0.0032	0.4478	0.0061
90	100	523	0.0442	0.0020	0.4920	0.0081
100	120	861	0.0727	0.0051	0.5647	0.0132
120	140	822	0.0694	0.0081	0.6341	0.0213
140	160	696	0.0588	0.0105	0.6929	0.0318
160	180	551	0.0465	0.0121	0.7395	0.0439
180	200	575	0.0486	0.0177	0.7881	0.0616
200	230	565	0.0477	0.0251	0.8358	0.0867
230	260	309	0.0261	0.0204	0.8619	0.1071
260	290	204	0.0172	0.0190	0.8791	0.1261
290	320	284	0.0240	0.0361	0.9031	0.1622
320	360	256	0.0216	0.0451	0.9247	0.2072
360	400	183	0.0155	0.0450	0.9402	0.2522
400	460	193	0.0163	0.0687	0.9565	0.3209
460	520	130	0.0110	0.0685	0.9675	0.3894
520	580	80	0.0068	0.0596	0.9742	0.4490
580	640	141	0.0119	0.1433	0.9861	0.5924
640	720	55	0.0046	0.0774	0.9908	0.6698
720	800	55	0.0046	0.1081	0.9954	0.7780
800	920	27	0.0023	0.0769	0.9977	0.8549
920	1040	16	0.0014	0.0674	0.9991	0.9223
1040	1160	6	0.0005	0.0358	0.9996	0.9581
1160	1280	1	0.0001	0.0081	0.9997	0.9662
1280	1440	3	0.0003	0.0338	0.9999	1.0000

TEST NUMBER 10 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	8	0.0015	0.0000	0.0015	0.0000
10	20	223	0.0417	0.0000	0.0432	0.0000
20	30	405	0.0757	0.0001	0.1188	0.0001
30	40	367	0.0686	0.0002	0.1874	0.0003
40	50	300	0.0561	0.0003	0.2435	0.0006
50	60	338	0.0632	0.0006	0.3066	0.0012
60	70	356	0.0665	0.0011	0.3731	0.0023
70	80	292	0.0546	0.0014	0.4277	0.0037
80	90	545	0.1018	0.0038	0.5295	0.0076
90	100	231	0.0432	0.0023	0.5727	0.0098
100	120	376	0.0703	0.0057	0.6429	0.0155
120	140	332	0.0620	0.0083	0.7050	0.0238
140	160	294	0.0549	0.0113	0.7599	0.0352
160	180	207	0.0387	0.0116	0.7986	0.0468
180	200	235	0.0439	0.0184	0.8425	0.0652
200	230	188	0.0351	0.0213	0.8776	0.0865
230	260	141	0.0263	0.0237	0.9040	0.1101
260	290	102	0.0191	0.0242	0.9230	0.1344
290	320	70	0.0131	0.0227	0.9361	0.1570
320	360	65	0.0121	0.0292	0.9482	0.1862
360	400	70	0.0131	0.0438	0.9613	0.2300
400	460	68	0.0127	0.0617	0.9740	0.2917
460	520	14	0.0026	0.0188	0.9766	0.3105
520	580	49	0.0092	0.0930	0.9858	0.4035
580	640	21	0.0039	0.0544	0.9897	0.4579
640	720	13	0.0024	0.0466	0.9922	0.5045
720	800	21	0.0039	0.1052	0.9961	0.6097
800	920	9	0.0017	0.0653	0.9978	0.6750
920	1040	2	0.0004	0.0215	0.9981	0.6965
1040	1160	2	0.0004	0.0304	0.9985	0.7269
1160	1280	6	0.0011	0.1243	0.9996	0.8512
1280	1440	0	0.0	0.0	0.9996	0.8512
1440	1600	1	0.0002	0.0401	0.9998	0.8913
1600	1800	0	0.0	0.0	0.9998	0.8913
1800	2000	0	0.0	0.0	0.9998	0.8913
2000	2240	1	0.0002	0.1087	1.0000	1.0000

TEST NUMBER 11 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	10	0.0038	0.0000	0.0038	0.0000
10	20	47	0.0180	0.0000	0.0218	0.0000
20	30	69	0.0264	0.0000	0.0483	0.0000
30	40	70	0.0268	0.0001	0.0751	0.0002
40	50	71	0.0272	0.0002	0.1023	0.0004
50	60	74	0.0283	0.0005	0.1306	0.0009
60	70	90	0.0345	0.0009	0.1651	0.0018
70	80	98	0.0375	0.0016	0.2026	0.0034
80	90	192	0.0735	0.0045	0.2761	0.0079
90	100	117	0.0448	0.0038	0.3209	0.0117
100	120	213	0.0816	0.0108	0.4025	0.0225
120	140	209	0.0800	0.0174	0.4826	0.0399
140	160	210	0.0804	0.0269	0.5630	0.0668
160	180	190	0.0728	0.0355	0.6358	0.1023
180	200	254	0.0973	0.0662	0.7331	0.1685
200	230	148	0.0567	0.0559	0.7897	0.2244
230	260	103	0.0394	0.0576	0.8292	0.2820
260	290	121	0.0463	0.0956	0.8755	0.3776
290	320	116	0.0444	0.1251	0.9200	0.5027
320	360	83	0.0318	0.1240	0.9517	0.6267
360	400	76	0.0291	0.1585	0.9808	0.7851
400	460	29	0.0111	0.0876	0.9920	0.8728
460	520	11	0.0042	0.0492	0.9962	0.9219
520	580	5	0.0019	0.0316	0.9981	0.9535
580	640	4	0.0015	0.0345	0.9996	0.9881
640	720	1	0.0004	0.0119	1.0000	1.0000

TEST NUMBER 14 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	4	0.0025	0.0000	0.0025	0.0000
10	20	22	0.0137	0.0000	0.0162	0.0000
20	30	24	0.0150	0.0000	0.0312	0.0000
30	40	23	0.0144	0.0000	0.0456	0.0001
40	50	62	0.0387	0.0002	0.0844	0.0003
50	60	38	0.0237	0.0002	0.1081	0.0005
60	70	40	0.0250	0.0004	0.1331	0.0009
70	80	33	0.0206	0.0005	0.1537	0.0014
80	90	86	0.0537	0.0019	0.2075	0.0034
90	100	25	0.0156	0.0008	0.2231	0.0041
100	120	110	0.0687	0.0054	0.2919	0.0095
120	140	108	0.0675	0.0087	0.3594	0.0183
140	160	99	0.0619	0.0123	0.4212	0.0306
160	180	114	0.0712	0.0206	0.4925	0.0512
180	200	131	0.0819	0.0331	0.5744	0.0843
200	230	148	0.0925	0.0542	0.6669	0.1384
230	260	93	0.0581	0.0504	0.7250	0.1888
260	290	91	0.0569	0.0697	0.7819	0.2585
290	320	110	0.0687	0.1149	0.8506	0.3734
320	360	68	0.0425	0.0984	0.8931	0.4718
360	400	102	0.0637	0.2061	0.9569	0.6779
400	460	33	0.0206	0.0966	0.9775	0.7745
460	520	12	0.0075	0.0520	0.9850	0.8265
520	580	15	0.0094	0.0919	0.9944	0.9183
580	640	7	0.0044	0.0585	0.9987	0.9768
640	720	2	0.0012	0.0232	1.0000	1.0000

TEST NUMBER 15 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	1	0.0002	0.0000	0.0002	0.0000
10	20	105	0.0188	0.0000	0.0190	0.0000
20	30	195	0.0349	0.0001	0.0539	0.0001
30	40	258	0.0462	0.0005	0.1002	0.0006
40	50	228	0.0409	0.0009	0.1410	0.0015
50	60	242	0.0434	0.0017	0.1844	0.0032
60	70	217	0.0389	0.0025	0.2233	0.0057
70	80	239	0.0428	0.0042	0.2661	0.0099
80	90	493	0.0884	0.0127	0.3545	0.0226
90	100	295	0.0529	0.0106	0.4073	0.0333
100	120	565	0.1013	0.0316	0.5086	0.0649
120	140	608	0.1090	0.0561	0.6176	0.1210
140	160	532	0.0953	0.0755	0.7129	0.1965
160	180	442	0.0792	0.0913	0.7921	0.2878
180	200	509	0.0912	0.1467	0.8833	0.4345
200	230	275	0.0493	0.1149	0.9326	0.5494
230	260	139	0.0249	0.0859	0.9575	0.6353
260	290	83	0.0149	0.0726	0.9724	0.7079
290	320	67	0.0120	0.0799	0.9844	0.7878
320	360	39	0.0070	0.0644	0.9914	0.8522
360	400	27	0.0048	0.0623	0.9962	0.9145
400	460	14	0.0025	0.0468	0.9987	0.9613
460	520	5	0.0009	0.0247	0.9996	0.9860
520	580	2	0.0004	0.0140	1.0000	1.0000

TEST NUMBER 16 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	181	0.0181	0.0000	0.0181	0.0000
10	20	694	0.0692	0.0002	0.0873	0.0002
20	30	781	0.0779	0.0009	0.1652	0.0011
30	40	792	0.0790	0.0026	0.2443	0.0037
40	50	788	0.0786	0.0055	0.3229	0.0093
50	60	775	0.0773	0.0099	0.4002	0.0192
60	70	781	0.0779	0.0165	0.4781	0.0357
70	80	700	0.0698	0.0227	0.5480	0.0584
80	90	1251	0.1248	0.0591	0.6728	0.1175
90	100	565	0.0564	0.0373	0.7292	0.1548
100	120	934	0.0932	0.0956	0.8224	0.2504
120	140	648	0.0647	0.1095	0.8870	0.3599
140	160	439	0.0438	0.1140	0.9309	0.4739
160	180	250	0.0249	0.0945	0.9558	0.5684
180	200	227	0.0227	0.1198	0.9784	0.6882
200	230	104	0.0104	0.0795	0.9888	0.7677
230	260	44	0.0044	0.0498	0.9932	0.8175
260	290	24	0.0024	0.0384	0.9956	0.8559
290	320	24	0.0024	0.0524	0.9980	0.9083
320	360	9	0.0009	0.0272	0.9989	0.9355
360	400	5	0.0005	0.0211	0.9994	0.9566
400	460	5	0.0005	0.0306	0.9999	0.9872
460	520	0	0.0	0.0	0.9999	0.9872
520	580	1	0.0001	0.0128	1.0000	1.0000

TEST NUMBER 18 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	161	0.0596	0.0002	0.0596	0.0002
20	30	259	0.0958	0.0015	0.1554	0.0017
30	40	256	0.0947	0.0041	0.2501	0.0058
40	50	239	0.0884	0.0081	0.3385	0.0139
50	60	233	0.0862	0.0144	0.4247	0.0283
60	70	222	0.0821	0.0227	0.5068	0.0510
70	80	207	0.0766	0.0325	0.5834	0.0834
80	90	344	0.1273	0.0786	0.7107	0.1620
90	100	195	0.0721	0.0622	0.7828	0.2242
100	120	234	0.0866	0.1158	0.8694	0.3400
120	140	148	0.0548	0.1209	0.9242	0.4609
140	160	86	0.0318	0.1079	0.9560	0.5688
160	180	56	0.0207	0.1023	0.9767	0.6711
180	200	31	0.0115	0.0791	0.9882	0.7502
200	230	20	0.0074	0.0739	0.9956	0.8241
230	260	13	0.0048	0.0711	1.0004	0.8952
260	290	4	0.0015	0.0309	1.0018	0.9261
290	320	7	0.0026	0.0739	1.0044	1.0000

TEST NUMBER 19 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	611	0.0440	0.0001	0.0440	0.0001
20	30	1425	0.1025	0.0006	0.1465	0.0007
30	40	1236	0.0889	0.0014	0.2354	0.0021
40	50	1127	0.0811	0.0028	0.3165	0.0049
50	60	1128	0.0811	0.0051	0.3976	0.0100
60	70	908	0.0653	0.0068	0.4629	0.0168
70	80	843	0.0606	0.0097	0.5236	0.0265
80	90	1407	0.1012	0.0236	0.6248	0.0501
90	100	713	0.0513	0.0167	0.6761	0.0667
100	120	1043	0.0750	0.0378	0.7511	0.1046
120	140	790	0.0568	0.0473	0.8079	0.1519
140	160	674	0.0485	0.0620	0.8564	0.2139
160	180	578	0.0416	0.0774	0.8980	0.2913
180	200	511	0.0368	0.0955	0.9348	0.3869
200	230	326	0.0235	0.0883	0.9582	0.4752
230	260	216	0.0155	0.0866	0.9737	0.5618
260	290	161	0.0116	0.0913	0.9853	0.6530
290	320	88	0.0063	0.0681	0.9917	0.7211
320	360	85	0.0061	0.0911	0.9978	0.8122
360	400	50	0.0036	0.0748	1.0014	0.8870
400	460	18	0.0013	0.0390	1.0027	0.9260
460	520	6	0.0004	0.0192	1.0031	0.9452
520	580	5	0.0004	0.0227	1.0035	0.9679
580	640	1	0.0001	0.0062	1.0035	0.9741
640	720	1	0.0001	0.0086	1.0036	0.9827
720	800	0	0.0	0.0	1.0036	0.9827
800	920	1	0.0001	0.0173	1.0037	1.0000

TEST NUMBER 20 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	822	0.0344	0.0000	0.0344	0.0000
20	30	2332	0.0977	0.0002	0.1321	0.0003
30	40	2253	0.0944	0.0006	0.2264	0.0009
40	50	2017	0.0845	0.0012	0.3109	0.0021
50	60	1751	0.0733	0.0019	0.3842	0.0041
60	70	1573	0.0659	0.0029	0.4501	0.0070
70	80	1358	0.0569	0.0038	0.5070	0.0108
80	90	2313	0.0969	0.0095	0.6039	0.0203
90	100	960	0.0402	0.0055	0.6441	0.0258
100	120	1689	0.0707	0.0150	0.7148	0.0408
120	140	1298	0.0544	0.0190	0.7692	0.0598
140	160	908	0.0380	0.0205	0.8072	0.0802
160	180	745	0.0312	0.0244	0.8384	0.1047
180	200	1000	0.0419	0.0458	0.8803	0.1504
200	230	712	0.0298	0.0472	0.9101	0.1977
230	260	531	0.0222	0.0521	0.9323	0.2498
260	290	394	0.0165	0.0547	0.9488	0.3045
290	320	382	0.0160	0.0723	0.9648	0.3768
320	360	251	0.0105	0.0658	0.9753	0.4426
360	400	246	0.0103	0.0901	0.9856	0.5327
400	460	153	0.0064	0.0812	0.9920	0.6139
460	520	116	0.0049	0.0911	0.9969	0.7050
520	580	52	0.0022	0.0577	0.9991	0.7627
580	640	49	0.0021	0.0742	1.0011	0.8369
640	720	34	0.0014	0.0713	1.0026	0.9083
720	800	14	0.0006	0.0410	1.0031	0.9493
800	920	7	0.0003	0.0297	1.0034	0.9790
920	1040	0	0.0	0.0	1.0034	0.9790
1040	1160	1	0.0000	0.0089	1.0035	0.9879
1160	1280	1	0.0000	0.0121	1.0035	1.0000

TEST NUMBER 21 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	11	0.0027	0.0000	0.0027	0.0000
10	20	151	0.0370	0.0000	0.0396	0.0000
20	30	195	0.0477	0.0001	0.0874	0.0001
30	40	210	0.0514	0.0003	0.1388	0.0005
40	50	239	0.0585	0.0008	0.1973	0.0013
50	60	240	0.0587	0.0015	0.2560	0.0028
60	70	229	0.0560	0.0023	0.3120	0.0051
70	80	239	0.0585	0.0037	0.3705	0.0088
80	90	364	0.0891	0.0083	0.4596	0.0171
90	100	219	0.0536	0.0070	0.5132	0.0241
100	120	286	0.0700	0.0141	0.5832	0.0383
120	140	254	0.0622	0.0207	0.6454	0.0590
140	160	194	0.0475	0.0243	0.6929	0.0833
160	180	200	0.0489	0.0365	0.7418	0.1198
180	200	257	0.0629	0.0655	0.8047	0.1852
200	230	236	0.0578	0.0871	0.8625	0.2724
230	260	151	0.0370	0.0825	0.8994	0.3548
260	290	127	0.0311	0.0981	0.9305	0.4529
290	320	108	0.0264	0.1138	0.9569	0.5667
320	360	72	0.0176	0.1051	0.9745	0.6718
360	400	59	0.0144	0.1202	0.9890	0.7920
400	460	27	0.0066	0.0797	0.9956	0.8718
460	520	7	0.0017	0.0306	0.9973	0.9023
520	580	6	0.0015	0.0371	0.9988	0.9394
580	640	3	0.0007	0.0253	0.9995	0.9647
640	720	1	0.0002	0.0117	0.9998	0.9764
720	800	0	0.0	0.0	0.9998	0.9764
800	920	1	0.0002	0.0236	1.0000	1.0000

TEST NUMBER 22 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	288	0.0583	0.0000	0.0583	0.0000
10	20	332	0.0672	0.0000	0.1254	0.0000
20	30	354	0.0716	0.0002	0.1970	0.0003
30	40	343	0.0694	0.0006	0.2664	0.0008
40	50	349	0.0706	0.0012	0.3370	0.0020
50	60	306	0.0619	0.0019	0.3989	0.0040
60	70	296	0.0599	0.0031	0.4587	0.0071
70	80	265	0.0536	0.0043	0.5123	0.0114
80	90	462	0.0934	0.0108	0.6058	0.0222
90	100	166	0.0336	0.0054	0.6394	0.0276
100	120	322	0.0651	0.0164	0.7045	0.0440
120	140	236	0.0477	0.0198	0.7522	0.0638
140	160	219	0.0443	0.0282	0.7965	0.0921
160	180	150	0.0303	0.0282	0.8269	0.1202
180	200	193	0.0390	0.0506	0.8659	0.1708
200	230	184	0.0372	0.0699	0.9031	0.2407
230	260	120	0.0243	0.0674	0.9274	0.3081
260	290	117	0.0237	0.0930	0.9511	0.4011
290	320	82	0.0166	0.0889	0.9676	0.4900
320	360	19	0.0038	0.0285	0.9715	0.5185
360	400	66	0.0133	0.1384	0.9848	0.6569
400	460	43	0.0087	0.1306	0.9935	0.7875
460	520	13	0.0026	0.0584	0.9962	0.8459
520	580	11	0.0022	0.0699	0.9984	0.9158
580	640	5	0.0010	0.0434	0.9994	0.9592
640	720	2	0.0004	0.0240	0.9998	0.9832
720	800	1	0.0002	0.0168	1.0000	1.0000

TEST NUMBER 23 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	165	0.0587	0.0000	0.0587	0.0000
10	20	180	0.0641	0.0001	0.1228	0.0001
20	30	221	0.0786	0.0004	0.2014	0.0004
30	40	220	0.0783	0.0010	0.2797	0.0014
40	50	232	0.0826	0.0023	0.3623	0.0037
50	60	182	0.0648	0.0032	0.4270	0.0069
60	70	181	0.0644	0.0053	0.4915	0.0122
70	80	151	0.0537	0.0068	0.5452	0.0190
80	90	257	0.0915	0.0168	0.6367	0.0359
90	100	101	0.0359	0.0092	0.6726	0.0451
100	120	168	0.0598	0.0239	0.7324	0.0690
120	140	135	0.0480	0.0316	0.7804	0.1006
140	160	109	0.0388	0.0392	0.8192	0.1399
160	180	98	0.0349	0.0514	0.8541	0.1912
180	200	134	0.0477	0.0981	0.9018	0.2893
200	230	92	0.0327	0.0976	0.9345	0.3868
230	260	65	0.0231	0.1020	0.9577	0.4888
260	290	48	0.0171	0.1065	0.9747	0.5953
290	320	30	0.0107	0.0908	0.9854	0.6861
320	360	16	0.0057	0.0671	0.9911	0.7532
360	400	16	0.0057	0.0937	0.9968	0.8469
400	460	5	0.0018	0.0424	0.9986	0.8893
460	520	1	0.0004	0.0126	0.9989	0.9019
520	580	1	0.0004	0.0178	0.9993	0.9196
580	640	0	0.0	0.0	0.9993	0.9196
640	720	1	0.0004	0.0335	0.9996	0.9532
720	800	1	0.0004	0.0468	1.0000	1.0000

TEST NUMBER 24 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	31	0.0876	0.0000	0.0876	0.0000
10	20	31	0.0876	0.0001	0.1751	0.0001
20	30	42	0.1186	0.0005	0.2938	0.0006
30	40	34	0.0960	0.0012	0.3898	0.0018
40	50	27	0.0763	0.0020	0.4661	0.0038
50	60	19	0.0537	0.0026	0.5198	0.0064
60	70	18	0.0508	0.0040	0.5706	0.0104
70	80	12	0.0339	0.0041	0.6045	0.0145
80	90	5	0.0141	0.0025	0.6186	0.0170
90	100	27	0.0763	0.0188	0.6949	0.0357
100	120	15	0.0424	0.0162	0.7373	0.0519
120	140	16	0.0452	0.0285	0.7825	0.0804
140	160	10	0.0282	0.0274	0.8107	0.1078
160	180	11	0.0311	0.0438	0.8418	0.1516
180	200	14	0.0395	0.0779	0.8814	0.2295
200	230	12	0.0339	0.0967	0.9153	0.3262
230	260	10	0.0282	0.1193	0.9435	0.4455
260	290	5	0.0141	0.0843	0.9576	0.5298
290	320	6	0.0169	0.1381	0.9746	0.6679
320	360	7	0.0198	0.2231	0.9943	0.8910
360	400	1	0.0028	0.0445	0.9972	0.9355
400	460	1	0.0028	0.0645	1.0000	1.0000

TEST NUMBER 26 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	182	0.0330	0.0000	0.0330	0.0000
20	30	435	0.0789	0.0002	0.1119	0.0002
30	40	429	0.0778	0.0005	0.1897	0.0006
40	50	401	0.0727	0.0009	0.2624	0.0016
50	60	406	0.0736	0.0017	0.3361	0.0033
60	70	340	0.0617	0.0023	0.3977	0.0056
70	80	371	0.0673	0.0039	0.4650	0.0095
80	90	625	0.1133	0.0096	0.5783	0.0192
90	100	283	0.0513	0.0061	0.6297	0.0253
100	120	437	0.0793	0.0146	0.7089	0.0399
120	140	326	0.0591	0.0180	0.7680	0.0579
140	160	295	0.0535	0.0250	0.8215	0.0829
160	180	173	0.0314	0.0214	0.8529	0.1043
180	200	194	0.0352	0.0334	0.8881	0.1377
200	230	150	0.0272	0.0375	0.9153	0.1751
230	260	109	0.0198	0.0403	0.9351	0.2154
260	290	74	0.0134	0.0387	0.9485	0.2541
290	320	75	0.0136	0.0535	0.9621	0.3075
320	360	53	0.0096	0.0523	0.9717	0.3599
360	400	57	0.0103	0.0786	0.9820	0.4385
400	460	32	0.0058	0.0639	0.9878	0.5024
460	520	27	0.0049	0.0798	0.9927	0.5822
520	580	10	0.0018	0.0418	0.9946	0.6240
580	640	8	0.0015	0.0456	0.9960	0.6696
640	720	6	0.0011	0.0474	0.9971	0.7170
720	800	12	0.0022	0.1323	0.9993	0.8494
800	920	3	0.0005	0.0479	0.9998	0.8973
920	1040	1	0.0002	0.0236	1.0000	0.9209
1040	1160	1	0.0002	0.0334	1.0002	0.9544
1160	1280	1	0.0002	0.0456	1.0004	1.0000
1280	1440	0	0.0	0.0	1.0004	1.0000

TEST NUMBER 27 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	89	0.0086	0.0000	0.0086	0.0000
10	20	543	0.0523	0.0000	0.0609	0.0000
20	30	655	0.0631	0.0000	0.1240	0.0000
30	40	611	0.0589	0.0001	0.1828	0.0002
40	50	637	0.0614	0.0002	0.2442	0.0004
50	60	616	0.0593	0.0004	0.3035	0.0008
60	70	563	0.0542	0.0006	0.3577	0.0014
70	80	598	0.0576	0.0010	0.4153	0.0024
80	90	1001	0.0964	0.0025	0.5118	0.0049
90	100	452	0.0435	0.0015	0.5553	0.0064
100	120	760	0.0732	0.0040	0.6285	0.0105
120	140	588	0.0566	0.0052	0.6851	0.0156
140	160	457	0.0440	0.0062	0.7291	0.0218
160	180	422	0.0406	0.0083	0.7698	0.0301
180	200	452	0.0435	0.0124	0.8133	0.0425
200	230	287	0.0276	0.0114	0.8410	0.0539
230	260	363	0.0350	0.0213	0.8759	0.0752
260	290	190	0.0183	0.0158	0.8942	0.0910
290	320	227	0.0219	0.0257	0.9161	0.1167
320	360	180	0.0173	0.0283	0.9334	0.1450
360	400	143	0.0138	0.0314	0.9472	0.1764
400	460	119	0.0115	0.0378	0.9587	0.2142
460	520	109	0.0105	0.0512	0.9692	0.2654
520	580	77	0.0074	0.0512	0.9766	0.3166
580	640	66	0.0064	0.0599	0.9830	0.3765
640	720	52	0.0050	0.0653	0.9880	0.4418
720	800	46	0.0044	0.0807	0.9924	0.5225
800	920	21	0.0020	0.0534	0.9944	0.5759
920	1040	17	0.0016	0.0639	0.9960	0.6399
1040	1160	18	0.0017	0.0957	0.9978	0.7356
1160	1280	12	0.0012	0.0871	0.9989	0.8227
1280	1440	7	0.0007	0.0704	0.9996	0.8931
1440	1600	1	0.0001	0.0140	0.9997	0.9071
1600	1800	0	0.0	0.0	0.9997	0.9071
1800	2000	2	0.0002	0.0548	0.9999	0.9619
2000	2240	1	0.0001	0.0381	1.0000	1.0000

TEST NUMBER 28 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	87	0.0059	0.0000	0.0059	0.0000
20	30	428	0.0288	0.0000	0.0347	0.0000
30	40	624	0.0420	0.0001	0.0767	0.0001
40	50	1375	0.0926	0.0004	0.1693	0.0006
50	60	0	0.0	0.0	0.1693	0.0006
60	70	635	0.0428	0.0006	0.2121	0.0012
70	80	575	0.0387	0.0008	0.2508	0.0020
80	90	1158	0.0780	0.0025	0.3288	0.0045
90	100	682	0.0459	0.0020	0.3747	0.0065
100	120	1156	0.0778	0.0053	0.4525	0.0118
120	140	1178	0.0793	0.0090	0.5319	0.0208
140	160	1038	0.0699	0.0121	0.6018	0.0329
160	180	880	0.0593	0.0150	0.6610	0.0479
180	200	956	0.0644	0.0227	0.7254	0.0706
200	230	809	0.0545	0.0279	0.7799	0.0985
230	260	665	0.0448	0.0339	0.8246	0.1324
260	290	455	0.0306	0.0328	0.8553	0.1652
290	320	609	0.0410	0.0599	0.8963	0.2251
320	360	430	0.0290	0.0586	0.9253	0.2836
360	400	426	0.0287	0.0810	0.9539	0.3646
400	460	276	0.0186	0.0760	0.9725	0.4407
460	520	188	0.0127	0.0766	0.9852	0.5173
520	580	111	0.0075	0.0640	0.9927	0.5813
580	640	109	0.0073	0.0857	1.0000	0.6670
640	720	77	0.0052	0.0839	1.0052	0.7509
720	800	53	0.0036	0.0806	1.0088	0.8316
800	920	24	0.0016	0.0529	1.0104	0.8845
920	1040	13	0.0009	0.0424	1.0112	0.9269
1040	1160	2	0.0001	0.0092	1.0114	0.9361
1160	1280	6	0.0004	0.0378	1.0118	0.9739
1280	1440	3	0.0002	0.0262	1.0120	1.0000

TEST NUMBER 29 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	24	0.0040	0.0000	0.0040	0.0000
10	20	183	0.0307	0.0000	0.0347	0.0000
20	30	252	0.0423	0.0001	0.0770	0.0001
30	40	240	0.0403	0.0003	0.1173	0.0004
40	50	250	0.0420	0.0007	0.1593	0.0011
50	60	286	0.0480	0.0014	0.2072	0.0026
60	70	261	0.0438	0.0022	0.2510	0.0047
70	80	317	0.0532	0.0040	0.3042	0.0087
80	90	579	0.0972	0.0107	0.4014	0.0194
90	100	261	0.0438	0.0067	0.4452	0.0262
100	120	602	0.1010	0.0241	0.5462	0.0503
120	140	449	0.0753	0.0297	0.6216	0.0800
140	160	435	0.0730	0.0442	0.6946	0.1242
160	180	380	0.0638	0.0562	0.7583	0.1804
180	200	413	0.0693	0.0853	0.8277	0.2656
200	230	341	0.0572	0.1020	0.8849	0.3676
230	260	248	0.0416	0.1098	0.9265	0.4774
260	290	169	0.0284	0.1058	0.9549	0.5832
290	320	107	0.0180	0.0914	0.9728	0.6746
320	360	75	0.0126	0.0887	0.9854	0.7633
360	400	43	0.0072	0.0710	0.9926	0.8343
400	460	19	0.0032	0.0455	0.9958	0.8798
460	520	15	0.0025	0.0531	0.9983	0.9329
520	580	5	0.0008	0.0250	0.9992	0.9579
580	640	2	0.0003	0.0137	0.9995	0.9716
640	720	3	0.0005	0.0284	1.0000	1.0000

TEST NUMBER 30 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	31	0.0300	0.0000	0.0300	0.0000
10	20	47	0.0455	0.0000	0.0754	0.0000
20	30	67	0.0648	0.0001	0.1402	0.0001
30	40	52	0.0503	0.0003	0.1905	0.0004
40	50	66	0.0638	0.0007	0.2544	0.0012
50	60	52	0.0503	0.0011	0.3046	0.0022
60	70	35	0.0338	0.0012	0.3385	0.0034
70	80	58	0.0561	0.0030	0.3946	0.0064
80	90	105	0.1015	0.0079	0.4961	0.0144
90	100	55	0.0532	0.0058	0.5493	0.0202
100	120	87	0.0841	0.0143	0.6335	0.0344
120	140	76	0.0735	0.0206	0.7070	0.0550
140	160	50	0.0484	0.0208	0.7553	0.0757
160	180	39	0.0377	0.0236	0.7930	0.0993
180	200	61	0.0590	0.0515	0.8520	0.1508
200	230	22	0.0213	0.0269	0.8733	0.1777
230	260	21	0.0203	0.0380	0.8936	0.2157
260	290	25	0.0242	0.0640	0.9178	0.2797
290	320	29	0.0280	0.1013	0.9458	0.3810
320	360	13	0.0126	0.0629	0.9584	0.4439
360	400	18	0.0174	0.1216	0.9758	0.5655
400	460	10	0.0097	0.0979	0.9855	0.6633
460	520	8	0.0077	0.1158	0.9932	0.7792
520	580	3	0.0029	0.0614	0.9961	0.8406
580	640	1	0.0010	0.0279	0.9971	0.8686
640	720	2	0.0019	0.0774	0.9990	0.9460
720	800	1	0.0010	0.0540	1.0000	1.0000

TEST NUMBER 31 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	8	0.0100	0.0000	0.0100	0.0000
10	20	12	0.0151	0.0000	0.0251	0.0000
20	30	28	0.0351	0.0001	0.0602	0.0001
30	40	53	0.0665	0.0006	0.1267	0.0008
40	50	48	0.0602	0.0012	0.1870	0.0020
50	60	47	0.0590	0.0022	0.2459	0.0041
60	70	39	0.0489	0.0030	0.2949	0.0071
70	80	44	0.0552	0.0052	0.3501	0.0123
80	90	80	0.1004	0.0136	0.4504	0.0259
90	100	43	0.0540	0.0102	0.5044	0.0361
100	120	58	0.0728	0.0214	0.5772	0.0576
120	140	51	0.0640	0.0311	0.6412	0.0887
140	160	42	0.0527	0.0393	0.6939	0.1280
160	180	36	0.0452	0.0491	0.7390	0.1771
180	200	64	0.0803	0.1218	0.8193	0.2989
200	230	79	0.0991	0.2179	0.9184	0.5168
230	260	22	0.0276	0.0898	0.9460	0.6066
260	290	16	0.0201	0.0923	0.9661	0.6990
290	320	16	0.0201	0.1260	0.9862	0.8249
320	360	7	0.0088	0.0764	0.9950	0.9013
360	400	2	0.0025	0.0305	0.9975	0.9318
400	460	1	0.0013	0.0221	0.9987	0.9538
460	520	0	0.0	0.0	0.9987	0.9538
520	580	1	0.0013	0.0462	1.0000	1.0000

TEST NUMBER 32 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	105	0.0540	0.0000	0.0540	0.0000
10	20	124	0.0637	0.0001	0.1177	0.0001
20	30	135	0.0694	0.0007	0.1871	0.0009
30	40	125	0.0642	0.0019	0.2513	0.0027
40	50	118	0.0606	0.0037	0.3119	0.0065
50	60	148	0.0761	0.0085	0.3880	0.0150
60	70	101	0.0519	0.0096	0.4399	0.0246
70	80	122	0.0627	0.0178	0.5026	0.0424
80	90	211	0.1084	0.0449	0.6110	0.0874
90	100	91	0.0468	0.0270	0.6578	0.1144
100	120	160	0.0822	0.0738	0.7400	0.1882
120	140	156	0.0802	0.1188	0.8201	0.3070
140	160	118	0.0606	0.1380	0.8808	0.4450
160	180	117	0.0601	0.1992	0.9409	0.6442
180	200	81	0.0416	0.1925	0.9825	0.8367
200	230	22	0.0113	0.0758	0.9938	0.9125
230	260	2	0.0010	0.0102	0.9949	0.9227
260	290	8	0.0041	0.0577	0.9990	0.9803
290	320	2	0.0010	0.0197	1.0000	1.0000

TEST NUMBER 33 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	3	0.0020	0.0000	0.0020	0.0000
10	20	8	0.0053	0.0000	0.0073	0.0000
20	30	27	0.0179	0.0000	0.0252	0.0000
30	40	24	0.0159	0.0000	0.0411	0.0001
40	50	33	0.0219	0.0001	0.0630	0.0002
50	60	40	0.0265	0.0003	0.0895	0.0005
60	70	34	0.0225	0.0004	0.1120	0.0009
70	80	38	0.0252	0.0007	0.1372	0.0017
80	90	89	0.0590	0.0025	0.1962	0.0042
90	100	58	0.0384	0.0023	0.2346	0.0064
100	120	110	0.0729	0.0067	0.3075	0.0131
120	140	117	0.0775	0.0117	0.3850	0.0248
140	160	110	0.0729	0.0169	0.4579	0.0418
160	180	101	0.0669	0.0226	0.5249	0.0644
180	200	126	0.0835	0.0394	0.6083	0.1039
200	230	145	0.0961	0.0658	0.7044	0.1697
230	260	93	0.0616	0.0624	0.7661	0.2321
260	290	89	0.0590	0.0845	0.8250	0.3166
290	320	77	0.0510	0.0997	0.8761	0.4163
320	360	74	0.0490	0.1328	0.9251	0.5490
360	400	27	0.0179	0.0676	0.9430	0.6167
400	460	62	0.0411	0.2250	0.9841	0.8417
460	520	12	0.0080	0.0644	0.9920	0.9061
520	580	11	0.0073	0.0835	0.9993	0.9896
580	640	1	0.0007	0.0104	1.0000	1.0000

TEST NUMBER 34 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	936	0.0478	0.0000	0.0478	0.0000
20	30	1990	0.1016	0.0003	0.1494	0.0003
30	40	2010	0.1026	0.0009	0.2520	0.0012
40	50	1751	0.0894	0.0016	0.3414	0.0028
50	60	1449	0.0740	0.0024	0.4154	0.0052
60	70	1311	0.0669	0.0036	0.4824	0.0088
70	80	1147	0.0586	0.0049	0.5409	0.0137
80	90	1992	0.1017	0.0123	0.6426	0.0260
90	100	776	0.0396	0.0067	0.6823	0.0327
100	120	1312	0.0670	0.0175	0.7492	0.0502
120	140	1183	0.0604	0.0261	0.8096	0.0763
140	160	905	0.0462	0.0307	0.8559	0.1070
160	180	477	0.0244	0.0235	0.8802	0.1305
180	200	721	0.0368	0.0497	0.9170	0.1801
200	230	372	0.0190	0.0371	0.9360	0.2173
230	260	344	0.0176	0.0508	0.9536	0.2680
260	290	222	0.0113	0.0464	0.9649	0.3144
290	320	207	0.0106	0.0590	0.9755	0.3734
320	360	126	0.0064	0.0497	0.9819	0.4231
360	400	135	0.0069	0.0744	0.9888	0.4975
400	460	72	0.0037	0.0575	0.9925	0.5549
460	520	77	0.0039	0.0910	0.9964	0.6459
520	580	33	0.0017	0.0551	0.9981	0.7010
580	640	19	0.0010	0.0433	0.9991	0.7443
640	720	15	0.0008	0.0474	0.9998	0.7917
720	800	16	0.0008	0.0705	1.0007	0.8622
800	920	10	0.0005	0.0639	1.0012	0.9260
920	1040	5	0.0003	0.0472	1.0014	0.9733
1040	1160	2	0.0001	0.0267	1.0015	1.0000

TEST NUMBER 41 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	11	0.0010	0.0000	0.0010	0.0000
10	20	572	0.0521	0.0000	0.0531	0.0000
20	30	817	0.0744	0.0001	0.1274	0.0001
30	40	819	0.0745	0.0002	0.2019	0.0003
40	50	817	0.0744	0.0004	0.2763	0.0007
50	60	769	0.0700	0.0008	0.3463	0.0015
60	70	660	0.0601	0.0011	0.4064	0.0026
70	80	641	0.0583	0.0016	0.4647	0.0042
80	90	1029	0.0936	0.0038	0.5583	0.0080
90	100	441	0.0401	0.0023	0.5985	0.0103
100	120	674	0.0613	0.0054	0.6598	0.0157
120	140	495	0.0450	0.0065	0.7049	0.0222
140	160	431	0.0392	0.0087	0.7441	0.0310
160	180	423	0.0385	0.0125	0.7826	0.0435
180	200	384	0.0349	0.0158	0.8175	0.0593
200	230	373	0.0339	0.0223	0.8515	0.0816
230	260	214	0.0195	0.0189	0.8709	0.1005
260	290	231	0.0210	0.0289	0.8920	0.1294
290	320	186	0.0169	0.0317	0.9089	0.1611
320	360	242	0.0220	0.0572	0.9309	0.2183
360	400	191	0.0174	0.0630	0.9483	0.2813
400	460	162	0.0147	0.0774	0.9630	0.3588
460	520	109	0.0099	0.0771	0.9730	0.4359
520	580	110	0.0100	0.1100	0.9830	0.5459
580	640	71	0.0065	0.0969	0.9894	0.6428
640	720	56	0.0051	0.1059	0.9945	0.7487
720	800	30	0.0027	0.0792	0.9973	0.8279
800	920	16	0.0015	0.0612	0.9987	0.8891
920	1040	6	0.0005	0.0340	0.9993	0.9230
1040	1160	5	0.0005	0.0400	0.9997	0.9630
1160	1280	2	0.0002	0.0218	0.9999	0.9849
1280	1440	1	0.0001	0.0151	1.0000	1.0000

TEST NUMBER 42 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	19	0.0016	0.0000	0.0016	0.0000
10	20	235	0.0196	0.0000	0.0212	0.0000
20	30	392	0.0327	0.0000	0.0539	0.0000
30	40	479	0.0400	0.0001	0.0938	0.0002
40	50	423	0.0353	0.0003	0.1291	0.0005
50	60	514	0.0429	0.0006	0.1720	0.0011
60	70	452	0.0377	0.0009	0.2097	0.0020
70	80	514	0.0429	0.0016	0.2526	0.0035
80	90	1044	0.0871	0.0046	0.3396	0.0081
90	100	532	0.0444	0.0033	0.3840	0.0114
100	120	990	0.0826	0.0095	0.4666	0.0209
120	140	906	0.0756	0.0143	0.5422	0.0352
140	160	876	0.0731	0.0213	0.6152	0.0565
160	180	644	0.0537	0.0227	0.6689	0.0792
180	200	894	0.0746	0.0441	0.7435	0.1233
200	230	696	0.0581	0.0497	0.8016	0.1730
230	260	579	0.0483	0.0612	0.8499	0.2342
260	290	392	0.0327	0.0586	0.8826	0.2928
290	320	457	0.0381	0.0932	0.9207	0.3860
320	360	287	0.0239	0.0811	0.9446	0.4671
360	400	269	0.0224	0.1061	0.9671	0.5732
400	460	172	0.0143	0.0983	0.9814	0.6715
460	520	97	0.0081	0.0820	0.9895	0.7536
520	580	47	0.0039	0.0562	0.9934	0.8098
580	640	37	0.0031	0.0604	0.9965	0.8702
640	720	19	0.0016	0.0429	0.9981	0.9131
720	800	16	0.0013	0.0505	0.9994	0.9636
800	920	5	0.0004	0.0229	0.9998	0.9865
920	1040	2	0.0002	0.0135	1.0000	1.0000

TEST NUMBER 48 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	7	0.0012	0.0000	0.0012	0.0000
10	20	213	0.0359	0.0001	0.0371	0.0001
20	30	411	0.0693	0.0008	0.1063	0.0009
30	40	454	0.0765	0.0025	0.1828	0.0034
40	50	476	0.0802	0.0056	0.2631	0.0090
50	60	506	0.0853	0.0108	0.3483	0.0197
60	70	528	0.0890	0.0186	0.4373	0.0383
70	80	436	0.0735	0.0235	0.5108	0.0618
80	90	769	0.1296	0.0605	0.6404	0.1223
90	100	363	0.0612	0.0398	0.7016	0.1621
100	120	614	0.1035	0.1046	0.8050	0.2667
120	140	458	0.0772	0.1288	0.8822	0.3955
140	160	279	0.0470	0.1205	0.9292	0.5161
160	180	194	0.0327	0.1220	0.9619	0.6381
180	200	106	0.0179	0.0931	0.9798	0.7312
200	230	51	0.0086	0.0649	0.9884	0.7960
230	260	26	0.0044	0.0489	0.9928	0.8450
260	290	23	0.0039	0.0612	0.9966	0.9062
290	320	12	0.0020	0.0436	0.9987	0.9498
320	360	3	0.0005	0.0151	0.9992	0.9649
360	400	5	0.0008	0.0351	1.0000	1.0000

TEST NUMBER 49 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	6	0.0018	0.0000	0.0018	0.0000
10	20	124	0.0363	0.0000	0.0381	0.0000
20	30	241	0.0706	0.0002	0.1086	0.0002
30	40	188	0.0551	0.0003	0.1637	0.0005
40	50	226	0.0662	0.0008	0.2299	0.0013
50	60	187	0.0548	0.0013	0.2846	0.0026
60	70	181	0.0530	0.0020	0.3376	0.0046
70	80	197	0.0577	0.0034	0.3953	0.0080
80	90	345	0.1010	0.0086	0.4963	0.0166
90	100	159	0.0466	0.0055	0.5429	0.0221
100	120	287	0.0840	0.0155	0.6269	0.0376
120	140	228	0.0668	0.0203	0.6937	0.0580
140	160	212	0.0621	0.0290	0.7558	0.0870
160	180	157	0.0460	0.0313	0.8018	0.1183
180	200	166	0.0486	0.0462	0.8504	0.1646
200	230	111	0.0325	0.0448	0.8829	0.2093
230	260	86	0.0252	0.0513	0.9081	0.2607
260	290	60	0.0176	0.0507	0.9256	0.3113
290	320	50	0.0146	0.0576	0.9403	0.3689
320	360	67	0.0196	0.1069	0.9599	0.4758
360	400	77	0.0225	0.1715	0.9824	0.6474
400	460	30	0.0088	0.0968	0.9912	0.7442
460	520	3	0.0009	0.0143	0.9921	0.7585
520	580	19	0.0056	0.1283	0.9977	0.8869
580	640	2	0.0006	0.0184	0.9982	0.9053
640	720	4	0.0012	0.0511	0.9994	0.9564
720	800	1	0.0003	0.0178	0.9997	0.9742
800	920	1	0.0003	0.0258	1.0000	1.0000

TEST NUMBER 51 — DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	63	0.0034	0.0000	0.0034	0.0000
10	20	933	0.0504	0.0001	0.0538	0.0001
20	30	1738	0.0939	0.0004	0.1476	0.0005
30	40	1795	0.0969	0.0012	0.2446	0.0017
40	50	1472	0.0795	0.0021	0.3241	0.0038
50	60	1399	0.0755	0.0037	0.3996	0.0075
60	70	1220	0.0659	0.0053	0.4655	0.0129
70	80	1242	0.0671	0.0083	0.5326	0.0212
80	90	1689	0.0912	0.0165	0.6238	0.0377
90	100	907	0.0490	0.0124	0.6728	0.0501
100	120	1279	0.0691	0.0271	0.7418	0.0772
120	140	1008	0.0544	0.0352	0.7963	0.1124
140	160	864	0.0467	0.0464	0.8429	0.1588
160	180	770	0.0416	0.0602	0.8845	0.2190
180	200	715	0.0386	0.0780	0.9231	0.2971
200	230	432	0.0233	0.0683	0.9464	0.3654
230	260	294	0.0159	0.0688	0.9623	0.4342
260	290	199	0.0107	0.0659	0.9731	0.5001
290	320	190	0.0103	0.0858	0.9833	0.5859
320	360	106	0.0057	0.0663	0.9890	0.6522
360	400	95	0.0051	0.0830	0.9942	0.7352
400	460	52	0.0028	0.0658	0.9970	0.8009
460	520	21	0.0011	0.0393	0.9981	0.8403
520	580	17	0.0009	0.0450	0.9990	0.8853
580	640	6	0.0003	0.0217	0.9994	0.9070
640	720	5	0.0003	0.0250	0.9996	0.9320
720	800	4	0.0002	0.0279	0.9998	0.9599
800	920	1	0.0001	0.0101	0.9999	0.9700
920	1040	2	0.0001	0.0300	1.0000	1.0000

TEST NUMBER 53 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	65	0.0073	0.0000	0.0073	0.0000
10	20	469	0.0530	0.0002	0.0603	0.0002
20	30	655	0.0740	0.0010	0.1344	0.0011
30	40	672	0.0759	0.0028	0.2103	0.0039
40	50	720	0.0814	0.0063	0.2917	0.0102
50	60	748	0.0845	0.0119	0.3762	0.0221
60	70	718	0.0811	0.0189	0.4573	0.0410
70	80	670	0.0757	0.0271	0.5331	0.0681
80	90	1235	0.1396	0.0727	0.6726	0.1408
90	100	520	0.0588	0.0427	0.7314	0.1836
100	120	831	0.0939	0.1060	0.8253	0.2896
120	140	570	0.0644	0.1201	0.8897	0.4097
140	160	405	0.0458	0.1310	0.9355	0.5407
160	180	248	0.0280	0.1168	0.9635	0.6575
180	200	166	0.0188	0.1092	0.9823	0.7667
200	230	92	0.0104	0.0877	0.9927	0.8543
230	260	32	0.0036	0.0451	0.9963	0.8994
260	290	15	0.0017	0.0299	0.9980	0.9294
290	320	11	0.0012	0.0299	0.9992	0.9593
320	360	3	0.0003	0.0113	0.9995	0.9706
360	400	2	0.0002	0.0105	0.9998	0.9811
400	460	1	0.0001	0.0076	0.9999	0.9887
460	520	1	0.0001	0.0113	1.0000	1.0000

TEST NUMBER 54 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	6	0.0014	0.0000	0.0014	0.0000
10	20	71	0.0164	0.0000	0.0178	0.0000
20	30	110	0.0255	0.0001	0.0433	0.0001
30	40	152	0.0352	0.0003	0.0785	0.0004
40	50	174	0.0403	0.0007	0.1187	0.0011
50	60	162	0.0375	0.0012	0.1562	0.0023
60	70	180	0.0417	0.0023	0.1979	0.0046
70	80	217	0.0502	0.0042	0.2481	0.0088
80	90	419	0.0970	0.0118	0.3451	0.0205
90	100	228	0.0528	0.0089	0.3978	0.0295
100	120	434	0.1004	0.0264	0.4983	0.0559
120	140	389	0.0900	0.0390	0.5883	0.0949
140	160	403	0.0933	0.0621	0.6816	0.1571
160	180	355	0.0822	0.0797	0.7637	0.2367
180	200	405	0.0937	0.1269	0.8574	0.3637
200	230	232	0.0537	0.1053	0.9111	0.4690
230	260	142	0.0329	0.0954	0.9440	0.5644
260	290	102	0.0236	0.0969	0.9676	0.6614
290	320	67	0.0155	0.0869	0.9831	0.7482
320	360	6	0.0014	0.0108	0.9845	0.7590
360	400	47	0.0109	0.1178	0.9954	0.8768
400	460	9	0.0021	0.0327	0.9975	0.9095
460	520	5	0.0012	0.0269	0.9986	0.9364
520	580	3	.0007	0.0228	0.9993	0.9592
580	640	2	0.0005	0.0207	0.9998	0.9799
640	720	0	0.0	0.0	0.9998	0.9799
720	800	1	0.0002	0.0201	1.0000	1.0000

TEST NUMBER 55 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	40	0.0152	0.0000	0.0152	0.0000
20	30	88	0.0334	0.0000	0.0487	0.0000
30	40	83	0.0315	0.0000	0.0802	0.0001
40	50	105	0.0399	0.0001	0.1201	0.0002
50	60	101	0.0384	0.0002	0.1585	0.0004
60	70	98	0.0372	0.0003	0.1957	0.0007
70	80	105	0.0399	0.0006	0.2357	0.0013
80	90	241	0.0916	0.0019	0.3273	0.0032
90	100	104	0.0395	0.0011	0.3668	0.0043
100	120	217	0.0825	0.0037	0.4493	0.0080
120	140	194	0.0737	0.0054	0.5230	0.0134
140	160	183	0.0696	0.0078	0.5926	0.0212
160	180	157	0.0597	0.0098	0.6522	0.0310
180	200	163	0.0620	0.0142	0.7142	0.0451
200	230	123	0.0468	0.0155	0.7609	0.0606
230	260	79	0.0300	0.0147	0.7910	0.0754
260	290	56	0.0213	0.0148	0.8122	0.0901
290	320	85	0.0323	0.0306	0.8445	0.1207
320	360	86	0.0327	0.0428	0.8772	0.1635
360	400	100	0.0380	0.0695	0.9152	0.2331
400	460	76	0.0289	0.0766	0.9441	0.3097
460	520	39	0.0148	0.0582	0.9590	0.3678
520	580	33	0.0125	0.0696	0.9715	0.4374
580	640	27	0.0103	0.0777	0.9818	0.5151
640	720	15	0.0057	0.0598	0.9875	0.5748
720	800	19	0.0072	0.1057	0.9947	0.6805
800	920	8	0.0030	0.0645	0.9977	0.7450
920	1040	8	0.0030	0.0954	1.0008	0.8405
1040	1160	4	0.0015	0.0675	1.0023	0.9079
1160	1280	4	0.0015	0.0921	1.0038	1.0000

TEST NUMBER 56 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	621	0.0399	0.0000	0.0399	0.0000
20	30	1288	0.0829	0.0002	0.1228	0.0002
30	40	1335	0.0859	0.0006	0.2087	0.0009
40	50	1318	0.0848	0.0013	0.2935	0.0022
50	60	1167	0.0751	0.0021	0.3685	0.0043
60	70	1042	0.0670	0.0031	0.4356	0.0074
70	80	1034	0.0665	0.0047	0.5021	0.0121
80	90	1631	0.1049	0.0109	0.6070	0.0230
90	100	688	0.0443	0.0064	0.6513	0.0294
100	120	1076	0.0692	0.0155	0.7205	0.0449
120	140	796	0.0512	0.0190	0.7717	0.0639
140	160	666	0.0428	0.0244	0.8145	0.0883
160	180	446	0.0287	0.0238	0.8432	0.1121
180	200	613	0.0394	0.0457	0.8827	0.1578
200	230	390	0.0251	0.0421	0.9078	0.1999
230	260	395	0.0254	0.0631	0.9332	0.2629
260	290	281	0.0181	0.0635	0.9512	0.3264
290	320	232	0.0149	0.0715	0.9662	0.3979
320	360	164	0.0106	0.0700	0.9767	0.4679
360	400	143	0.0092	0.0852	0.9859	0.5530
400	460	107	0.0069	0.0924	0.9928	0.6454
460	520	57	0.0037	0.0728	0.9965	0.7182
520	580	41	0.0026	0.0741	0.9991	0.7923
580	640	25	0.0016	0.0616	1.0007	0.8539
640	720	11	0.0007	0.0376	1.0014	0.8915
720	800	12	0.0008	0.0572	1.0022	0.9487
800	920	2	0.0001	0.0138	1.0023	0.9625
920	1040	1	0.0001	0.0102	1.0024	0.9727
1040	1160	0	0.0	0.0	1.0024	0.9727
1160	1280	0	0.0	0.0	1.0024	0.9727
1280	1440	1	0.0001	0.0273	1.0024	1.0000

TEST NUMBER 57 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	658	0.0400	0.0001	0.0400	0.0001
20	30	1455	0.0885	0.0005	0.1285	0.0006
30	40	1394	0.0848	0.0014	0.2133	0.0019
40	50	1339	0.0814	0.0028	0.2948	0.0047
50	60	1279	0.0778	0.0049	0.3726	0.0096
60	70	1219	0.0741	0.0076	0.4467	0.0172
70	80	1117	0.0679	0.0107	0.5147	0.0279
80	90	1921	0.1168	0.0269	0.6315	0.0548
90	100	743	0.0452	0.0145	0.6767	0.0694
100	120	1317	0.0801	0.0400	0.7568	0.1093
120	140	897	0.0546	0.0449	0.8114	0.1543
140	160	719	0.0437	0.0553	0.8551	0.2096
160	180	611	0.0372	0.0684	0.8923	0.2780
180	200	627	0.0381	0.0981	0.9304	0.3761
200	230	426	0.0259	0.0965	0.9563	0.4726
230	260	282	0.0172	0.0946	0.9735	0.5672
260	290	181	0.0110	0.0858	0.9845	0.6530
290	320	108	0.0066	0.0699	0.9911	0.7229
320	360	75	0.0046	0.0672	0.9955	0.7901
360	400	62	0.0038	0.0776	0.9994	0.8676
400	460	25	0.0015	0.0453	1.0009	0.9129
460	520	11	0.0007	0.0295	1.0016	0.9425
520	580	4	0.0002	0.0152	1.0018	0.9576
580	640	4	0.0002	0.0207	1.0021	0.9783
640	720	1	0.0001	0.0072	1.0021	0.9855
720	800	0	0.0	0.0	1.0021	0.9855
800	920	1	0.0001	0.0145	1.0022	1.0000

TEST NUMBER 58 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	66	0.0037	0.0000	0.0037	0.0000
10	20	1058	0.0593	0.0000	0.0630	0.0000
20	30	1374	0.0770	0.0002	0.1401	0.0003
30	40	1337	0.0750	0.0006	0.2150	0.0009
40	50	1174	0.0658	0.0012	0.2808	0.0020
50	60	1099	0.0616	0.0020	0.3425	0.0040
60	70	988	0.0554	0.0029	0.3978	0.0069
70	80	858	0.0481	0.0039	0.4460	0.0109
80	90	1640	0.0919	0.0109	0.5379	0.0217
90	100	650	0.0364	0.0060	0.5743	0.0277
100	120	1223	0.0686	0.0176	0.6429	0.0453
120	140	1012	0.0567	0.0240	0.6997	0.0693
140	160	1001	0.0561	0.0365	0.7558	0.1058
160	180	779	0.0437	0.0413	0.7995	0.1471
180	200	1012	0.0567	0.0749	0.8562	0.2220
200	230	764	0.0428	0.0820	0.8990	0.3040
230	260	563	0.0316	0.0894	0.9306	0.3933
260	290	346	0.0194	0.0777	0.9500	0.4710
290	320	322	0.0181	0.0986	0.9680	0.5696
320	360	221	0.0124	0.0938	0.9804	0.6633
360	400	187	0.0105	0.1108	0.9909	0.7741
400	460	74	0.0041	0.0635	0.9951	0.8376
460	520	43	0.0024	0.0546	0.9975	0.8922
520	580	27	0.0015	0.0485	0.9990	0.9407
580	640	9	0.0005	0.0220	0.9995	0.9627
640	720	4	0.0002	0.0136	0.9997	0.9763
720	800	5	0.0003	0.0237	1.0000	1.0000

TEST NUMBER 59 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	13	0.0019	0.0000	0.0019	0.0000
10	20	411	0.0591	0.0000	0.0610	0.0000
20	30	533	0.0767	0.0002	0.1376	0.0002
30	40	546	0.0785	0.0005	0.2162	0.0006
40	50	477	0.0686	0.0009	0.2848	0.0015
50	60	392	0.0564	0.0013	0.3411	0.0028
60	70	452	0.0650	0.0024	0.4062	0.0052
70	80	417	0.0600	0.0034	0.4661	0.0086
80	90	686	0.0987	0.0082	0.5648	0.0169
90	100	316	0.0454	0.0053	0.6102	0.0222
100	120	439	0.0631	0.0114	0.6734	0.0336
120	140	397	0.0571	0.0171	0.7305	0.0507
140	160	339	0.0488	0.0224	0.7792	0.0731
160	180	227	0.0326	0.0218	0.8119	0.0949
180	200	302	0.0434	0.0405	0.8553	0.1354
200	230	210	0.0302	0.0408	0.8855	0.1762
230	260	141	0.0203	0.0406	0.9058	0.2168
260	290	154	0.0221	0.0627	0.9279	0.2794
290	320	128	0.0184	0.0710	0.9464	0.3505
320	360	129	0.0186	0.0992	0.9649	0.4497
360	400	97	0.0140	0.1041	0.9789	0.5538
400	460	53	0.0076	0.0824	0.9865	0.6362
460	520	46	0.0066	0.1059	0.9931	0.7421
520	580	24	0.0035	0.0781	0.9965	0.8202
580	640	10	0.0014	0.0444	0.9980	0.8646
640	720	9	0.0013	0.0554	0.9993	0.9200
720	800	2	0.0003	0.0172	0.9996	0.9371
800	920	0	0.0	0.0	0.9996	0.9371
920	1040	2	0.0003	0.0368	0.9999	0.9740
1040	1160	1	0.0001	0.0260	1.0000	1.0000

TEST NUMBER 60 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	24	0.0023	0.0000	0.0023	0.0000
10	20	260	0.0244	0.0000	0.0267	0.0000
20	30	390	0.0366	0.0000	0.0633	0.0001
30	40	390	0.0366	0.0001	0.1000	0.0002
40	50	413	0.0388	0.0003	0.1388	0.0005
50	60	403	0.0379	0.0005	0.1766	0.0010
60	70	378	0.0355	0.0008	0.2122	0.0019
70	80	479	0.0450	0.0016	0.2572	0.0035
80	90	958	0.0900	0.0047	0.3472	0.0082
90	100	458	0.0430	0.0032	0.3902	0.0114
100	120	887	0.0833	0.0095	0.4736	0.0208
120	140	798	0.0750	0.0141	0.5485	0.0349
140	160	694	0.0652	0.0188	0.6137	0.0537
160	180	634	0.0596	0.0250	0.6733	0.0787
180	200	813	0.0764	0.0447	0.7497	0.1234
200	230	600	0.0564	0.0478	0.8061	0.1713
230	260	463	0.0435	0.0546	0.8496	0.2259
260	290	362	0.0340	0.0604	0.8836	0.2863
290	320	419	0.0394	0.0954	0.9230	0.3817
320	360	274	0.0257	0.0864	0.9487	0.4681
360	400	219	0.0206	0.0964	0.9693	0.5645
400	460	130	0.0122	0.0829	0.9815	0.6474
460	520	84	0.0079	0.0793	0.9894	0.7267
520	580	47	0.0044	0.0627	0.9938	0.7894
580	640	26	0.0024	0.0473	0.9962	0.8368
640	720	23	0.0022	0.0580	0.9984	0.8948
720	820	6	0.0006	0.0211	0.9990	0.9159
820	920	5	0.0005	0.0255	0.9994	0.9414
920	1040	3	0.0003	0.0227	0.9997	0.9641
1040	1160	2	0.0002	0.0214	0.9999	0.9854
1160	1280	1	0.0001	0.0146	1.0000	1.0000

TEST NUMBER 62 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	19	0.0076	0.0000	0.0076	0.0000
10	20	160	0.0642	0.0002	0.0718	0.0002
20	30	148	0.0594	0.0009	0.1312	0.0011
30	40	208	0.0834	0.0034	0.2146	0.0044
40	50	173	0.0694	0.0060	0.2840	0.0104
50	60	170	0.0682	0.0107	0.3522	0.0211
60	70	146	0.0586	0.0151	0.4107	0.0362
70	80	179	0.0718	0.0285	0.4826	0.0647
80	90	343	0.1376	0.0796	0.6201	0.1443
90	100	165	0.0662	0.0534	0.6863	0.1977
100	120	317	0.1272	0.1593	0.8135	0.3571
120	140	238	0.0955	0.1975	0.9089	0.5545
140	160	107	0.0429	0.1364	0.9519	0.6909
160	180	61	0.0245	0.1132	0.9763	0.8041
180	200	39	0.0156	0.1010	0.9920	0.9051
200	230	16	0.0064	0.0601	0.9984	0.9652
230	260	1	0.0004	0.0056	0.9988	0.9707
260	290	1	0.0004	0.0079	0.9992	0.9786
290	320	2	0.0008	0.0214	1.0000	1.0000

TEST NUMBER 63 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	162	0.0164	0.0000	0.0164	0.0000
20	30	818	0.0829	0.0003	0.0993	0.0003
30	40	759	0.0769	0.0006	0.1762	0.0009
40	50	682	0.0691	0.0012	0.2453	0.0021
50	60	710	0.0719	0.0023	0.3173	0.0045
60	70	619	0.0627	0.0034	0.3800	0.0078
70	80	569	0.0577	0.0047	0.4376	0.0126
80	90	1058	0.1072	0.0128	0.5448	0.0254
90	100	452	0.0458	0.0077	0.5906	0.0330
100	120	808	0.0819	0.0212	0.6725	0.0543
120	140	597	0.0605	0.0259	0.7330	0.0802
140	160	537	0.0544	0.0358	0.7874	0.1160
160	180	369	0.0374	0.0358	0.8248	0.1518
180	200	502	0.0509	0.0680	0.8757	0.2198
200	230	373	0.0378	0.0732	0.9135	0.2930
230	260	250	0.0253	0.0726	0.9388	0.3656
260	290	177	0.0179	0.0727	0.9567	0.4383
290	320	176	0.0178	0.0986	0.9746	0.5369
320	360	90	0.0091	0.0699	0.9837	0.6068
360	400	90	0.0091	0.0975	0.9928	0.7043
400	460	64	0.0065	0.1005	0.9993	0.8048
460	520	29	0.0029	0.0674	1.0022	0.8722
520	580	17	0.0017	0.0559	1.0040	0.9280
580	640	8	0.0008	0.0359	1.0048	0.9639
640	720	1	0.0001	0.0062	1.0049	0.9701
720	800	2	0.0002	0.0173	1.0051	0.9874
800	920	1	0.0001	0.0126	1.0052	1.0000

TEST NUMBER 64 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	9	0.0033	0.0000	0.0030	0.0000
10	20	120	0.0398	0.0001	0.0427	0.0001
20	30	169	0.0560	0.0003	0.0987	0.0004
30	40	188	0.0623	0.0010	0.1610	0.0014
40	50	216	0.0716	0.0024	0.2326	0.0038
50	60	194	0.0643	0.0040	0.2969	0.0078
60	70	191	0.0633	0.0065	0.3602	0.0143
70	80	218	0.0722	0.0114	0.4324	0.0256
80	90	371	0.1229	0.0281	0.5553	0.0538
90	100	129	0.0427	0.0137	0.5981	0.0674
100	120	299	0.0991	0.0491	0.6972	0.1166
120	140	219	0.0726	0.0594	0.7697	0.1760
140	160	200	0.0663	0.0834	0.8360	0.2593
160	180	124	0.0411	0.0752	0.8771	0.3346
180	200	147	0.0487	0.1245	0.9258	0.4591
200	230	72	0.0239	0.0884	0.9496	0.5474
230	260	66	0.0219	0.1199	0.9715	0.6673
260	290	46	0.0152	0.1181	0.9867	0.7854
290	320	23	0.0076	0.0806	0.9944	0.8660
320	360	13	0.0043	0.0631	0.9987	0.9291
360	400	1	0.0003	0.0068	0.9990	0.9359
400	460	0	0.0	0.0	0.9990	0.9359
460	520	3	0.0010	0.0436	1.0000	0.9795
520	580	1	0.0003	0.0205	1.0003	1.0000

TEST NUMBER 65 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	8	0.0006	0.0000	0.0006	0.0000
10	20	246	0.0173	0.0000	0.0179	0.0000
20	30	619	0.0435	0.0001	0.0614	0.0002
30	40	747	0.0526	0.0005	0.1140	0.0006
40	50	748	0.0526	0.0010	0.1666	0.0017
50	60	692	0.0487	0.0017	0.2153	0.0034
60	70	755	0.0531	0.0031	0.2684	0.0065
70	80	710	0.0499	0.0045	0.3183	0.0109
80	90	1610	0.1133	0.0147	0.4316	0.0257
90	100	743	0.0523	0.0095	0.4839	0.0352
100	120	1454	0.1023	0.0289	0.5861	0.0640
120	140	1350	0.0950	0.0442	0.6811	0.1083
140	160	976	0.0687	0.0491	0.7498	0.1574
160	180	833	0.0586	0.0610	0.8084	0.2184
180	200	948	0.0667	0.0970	0.8751	0.3154
200	230	565	0.0397	0.0837	0.9148	0.3992
230	260	372	0.0262	0.0816	0.9410	0.4808
260	290	299	0.0210	0.0927	0.9620	0.5735
290	320	214	0.0151	0.0906	0.9771	0.6640
320	360	121	0.0085	0.0709	0.9856	0.7350
360	400	111	0.0078	0.0908	0.9934	0.8258
400	460	43	0.0030	0.0510	0.9964	0.8768
460	520	27	0.0019	0.0474	0.9983	0.9242
520	580	13	0.0009	0.0323	0.9992	0.9564
580	640	9	0.0006	0.0305	0.9999	0.9869
640	720	0	0.0	0.0	0.9999	0.9869
720	800	2	0.0001	0.0131	1.0000	1.0000

TEST NUMBER 66 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	48	0.0075	0.0000	0.0075	0.0000
10	20	548	0.0859	0.0004	0.0935	0.0004
20	30	651	0.1021	0.0025	0.1956	0.0029
30	40	644	0.1010	0.0067	0.2966	0.0096
40	50	630	0.0988	0.0139	0.3954	0.0235
50	60	616	0.0966	0.0248	0.4920	0.0484
60	70	561	0.0880	0.0373	0.5800	0.0857
70	80	483	0.0758	0.0494	0.6557	0.1351
80	90	871	0.1366	0.1296	0.7923	0.2647
90	100	297	0.0466	0.0617	0.8389	0.3264
100	120	477	0.0748	0.1539	0.9137	0.4803
120	140	270	0.0423	0.1438	0.9561	0.6241
140	160	155	0.0243	0.1268	0.9804	0.7508
160	180	57	0.0089	0.0679	0.9893	0.8187
180	200	31	0.0049	0.0515	0.9942	0.8703
200	230	23	0.0036	0.0554	0.9978	0.9257
230	260	6	0.0009	0.0214	0.9987	0.9470
260	290	4	0.0006	0.0202	0.9994	0.9672
290	320	2	0.0003	0.0138	0.9997	0.9809
320	360	2	0.0003	0.0191	1.0000	1.0000

TEST NUMBER 67 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	248	0.0361	0.0000	0.0361	0.0000
20	30	353	0.0514	0.0002	0.0874	0.0002
30	40	372	0.0541	0.0005	0.1416	0.0007
40	50	447	0.0650	0.0012	0.2066	0.0019
50	60	394	0.0573	0.0019	0.2639	0.0038
60	70	389	0.0566	0.0031	0.3205	0.0069
70	80	379	0.0551	0.0047	0.3757	0.0116
80	90	812	0.1181	0.0147	0.4938	0.0263
90	100	359	0.0522	0.0091	0.5460	0.0353
100	120	599	0.0872	0.0234	0.6332	0.0588
120	140	533	0.0775	0.0344	0.7108	0.0932
140	160	448	0.0652	0.0445	0.7759	0.1377
160	180	294	0.0428	0.0425	0.8187	0.1801
180	200	348	0.0506	0.0702	0.8693	0.2503
200	230	265	0.0386	0.0774	0.9079	0.3278
230	260	163	0.0237	0.0705	0.9316	0.3982
260	290	160	0.0233	0.0978	0.9549	0.4961
290	320	131	0.0191	0.1093	0.9740	0.6054
320	360	53	0.0077	0.0613	0.9817	0.6666
360	400	73	0.0106	0.1178	0.9923	0.7844
400	460	36	0.0052	0.0842	0.9975	0.8686
460	520	15	0.0022	0.0519	0.9997	0.9205
520	580	5	0.0007	0.0245	1.0004	0.9449
580	640	3	0.0004	0.0200	1.0009	0.9649
640	720	1	0.0001	0.0092	1.0010	0.9742
720	800	2	0.0003	0.0258	1.0013	1.0000

TEST NUMBER 68 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	15	0.0035	0.0000	0.0035	0.0000
20	30	70	0.0163	0.0000	0.0198	0.0000
30	40	87	0.0203	0.0000	0.0401	0.0000
40	50	100	0.0233	0.0001	0.0634	0.0001
50	60	85	0.0198	0.0001	0.0832	0.0002
60	70	58	0.0135	0.0001	0.0967	0.0002
70	80	80	0.0186	0.0002	0.1153	0.0004
80	90	189	0.0440	0.0006	0.1593	0.0011
90	100	60	0.0140	0.0003	0.1733	0.0013
100	120	194	0.0452	0.0014	0.2185	0.0028
120	140	159	0.0370	0.0019	0.2555	0.0047
140	160	227	0.0529	0.0042	0.3084	0.0089
160	180	194	0.0452	0.0052	0.3536	0.0141
180	200	199	0.0464	0.0075	0.4000	0.0216
200	230	382	0.0890	0.0208	0.4889	0.0425
230	260	266	0.0620	0.0215	0.5509	0.0639
260	290	278	0.0648	0.0317	0.6157	0.0957
290	320	370	0.0862	0.0576	0.7018	0.1533
320	360	405	0.0943	0.0874	0.7962	0.2407
360	400	351	0.0818	0.1057	0.8779	0.3464
400	460	193	0.0450	0.0842	0.9229	0.4307
460	520	73	0.0170	0.0471	0.9399	0.4778
520	580	0	0.0	0.0	0.9399	0.4778
580	640	198	0.0461	0.2467	0.9860	0.7246
640	720	64	0.0149	0.1105	1.0009	0.8350
720	800	41	0.0096	0.0988	1.0105	0.9338
800	920	4	0.0009	0.0140	1.0114	0.9478
920	1040	2	0.0005	0.0103	1.0119	0.9581
1040	1160	3	0.0007	0.0219	1.0126	0.9801
1160	1280	2	0.0005	0.0199	1.0130	1.0000

TEST NUMBER 69 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	221	0.0357	0.0000	0.0357	0.0000
10	20	0	0.0	0.0	0.0357	0.0000
20	30	197	0.0319	0.0001	0.0676	0.0001
30	40	194	0.0314	0.0003	0.0990	0.0004
40	50	223	0.0361	0.0007	0.1350	0.0011
50	60	235	0.0380	0.0014	0.1730	0.0025
60	70	262	0.0424	0.0026	0.2154	0.0051
70	80	297	0.0480	0.0045	0.2634	0.0096
80	90	604	0.0977	0.0133	0.3611	0.0229
90	100	350	0.0566	0.0108	0.4177	0.0337
100	120	704	0.1138	0.0336	0.5315	0.0672
120	140	607	0.0982	0.0478	0.6297	0.1150
140	160	535	0.0865	0.0647	0.7162	0.1797
160	180	515	0.0833	0.0907	0.7995	0.2704
180	200	539	0.0872	0.1325	0.8866	0.4029
200	230	317	0.0513	0.1129	0.9379	0.5158
230	260	195	0.0315	0.1028	0.9694	0.6185
260	290	84	0.0136	0.0626	0.9830	0.6811
290	320	58	0.0094	0.0590	0.9924	0.7401
320	360	35	0.0057	0.0493	0.9981	0.7894
360	400	42	0.0068	0.0826	1.0049	0.8720
400	460	14	0.0023	0.0399	1.0071	0.9119
460	520	11	0.0018	0.0464	1.0089	0.9583
520	580	7	0.0011	0.0417	1.0100	1.0000

TEST NUMBER 70 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	107	0.0086	0.0000	0.0086	0.0000
10	20	660	0.0530	0.0001	0.0616	0.0001
20	30	749	0.0601	0.0005	0.1217	0.0006
30	40	770	0.0618	0.0014	0.1835	0.0020
40	50	814	0.0653	0.0032	0.2488	0.0052
50	60	803	0.0645	0.0057	0.3133	0.0109
60	70	793	0.0636	0.0093	0.3769	0.0202
70	80	784	0.0629	0.0141	0.4398	0.0343
80	90	1566	0.1257	0.0411	0.5655	0.0755
90	100	810	0.0650	0.0297	0.6305	0.1052
100	120	1296	0.1040	0.0738	0.7346	0.1789
120	140	1129	0.0906	0.1061	0.8252	0.2850
140	160	779	0.0625	0.1124	0.8877	0.3974
160	180	520	0.0417	0.1092	0.9294	0.5066
180	200	390	0.0313	0.1144	0.9608	0.6210
200	230	207	0.0166	0.0880	0.9774	0.7090
230	260	130	0.0104	0.0817	0.9878	0.7907
260	290	62	0.0050	0.0551	0.9928	0.8459
290	320	43	0.0035	0.0522	0.9962	0.8980
320	360	34	0.0027	0.0571	0.9990	0.9552
360	400	8	0.0006	0.0188	0.9996	0.9739
400	460	2	0.0002	0.0068	0.9998	0.9807
460	520	1	0.0001	0.0050	0.9998	0.9858
520	580	2	0.0002	0.0142	1.0000	1.0000

TEST NUMBER 71 -- DISTRIBUTION DATA

DROP SIZE CLASS, MICRONS		NUMBER OF DROPS IN CLASS	PORTION OF DROPS IN CLASS	PORTION OF VOLUME IN CLASS	SUM OF PORTION IN AND BELOW CLASS	SUM OF VOLUME IN AND BELOW CLASS
0	10	0	0.0	0.0	0.0	0.0
10	20	1	0.0122	0.0000	0.0122	0.0000
20	30	3	0.0366	0.0000	0.0488	0.0000
30	40	6	0.0732	0.0002	0.1220	0.0003
40	50	7	0.0854	0.0005	0.2073	0.0008
50	60	0	0.0	0.0	0.2073	0.0008
60	70	2	0.0244	0.0005	0.2317	0.0013
70	80	2	0.0244	0.0007	0.2561	0.0020
80	90	11	0.1341	0.0057	0.3902	0.0076
90	100	2	0.0244	0.0014	0.4146	0.0091
100	120	3	0.0366	0.0033	0.4512	0.0124
120	140	3	0.0366	0.0055	0.4878	0.0179
140	160	6	0.0732	0.0170	0.5610	0.0349
160	180	6	0.0732	0.0247	0.6341	0.0596
180	200	4	0.0488	0.0230	0.6829	0.0825
200	230	4	0.0488	0.0333	0.7317	0.1158
230	260	7	0.0854	0.0862	0.8171	0.2020
260	290	0	0.0	0.0	0.8171	0.2020
290	320	2	0.0244	0.0475	0.8415	0.2495
320	360	6	0.0732	0.1975	0.9146	0.4470
360	400	5	0.0610	0.2297	0.9756	0.6768
400	460	2	0.0244	0.1332	1.0000	0.8099
460	520	0	0.0	0.0	1.0000	0.8099
520	580	0	0.0	0.0	1.0000	0.8099
580	640	1	0.0122	0.1901	1.0122	1.0000

XV. APPENDIX D. COMPUTED STATISTICS OF CENTRAL TENDENCY

Test	Π_3	Π_2	θ radians	D_n microns	D_{VME} microns	D_{VH} microns	D_{MM} microns	D_{gN} microns	D_{gV} microns	D_{Saut} microns
4	23959	2776	1.134	101.2	155.5	306.0	274.7	76.8	267.5	230.1
5	22896	2653	0.663	122.1	216.5	514.2	474.8	88.0	443.3	366.9
6	23969	2777	1.920	131.4	185.0	328.4	291.6	103.8	290.1	253.8
9	13463	876	1.134	148.3	266.2	613.9	601.3	104.2	539.9	452.6
10	12866	837	0.663	126.5	253.9	845.6	712.2	88.0	667.4	500.1
11	13469	877	1.920	161.6	216.0	328.3	319.4	129.2	304.8	278.8
14	4222	190	1.117	197.3	257.0	372.6	365.5	158.6	349.0	323.0
15	7513	604	1.117	126.1	162.2	243.8	217.1	105.0	223.5	203.8
16	13352	1908	1.117	79.1	109.1	186.2	165.5	62.4	165.2	146.1
18	13308	1901	1.152	75.2	99.8	159.2	147.2	63.1	144.6	129.8
19	23760	8708	1.117	92.2	138.2	264.8	238.6	72.2	231.9	200.5
20	23951	8281	1.134	106.6	184.4	425.0	385.5	78.3	367.2	305.6
21	13478	2622	1.134	128.2	187.5	323.8	302.4	96.7	293.0	261.4
22	13452	2617	1.169	102.9	174.3	350.5	334.1	66.4	314.5	273.4
23	13495	2625	1.169	92.7	149.4	297.4	263.1	62.2	260.5	225.7
24	13489	2623	3.490	88.6	151.6	270.5	279.4	52.8	253.6	230.9
26	12247	2382	0.244	108.5	193.3	519.3	457.8	80.8	430.4	339.3
27	12880	2506	0.663	138.3	288.9	881.6	777.7	90.7	733.6	573.2
28	13965	2717	1.414	171.3	268.8	558.1	506.4	135.1	484.0	409.5
29	13483	2623	1.920	129.0	177.3	290.9	266.4	101.8	263.2	235.9
30	7573	828	1.134	121.5	198.8	397.3	378.5	83.8	355.3	307.2
31	7513	1461	1.117	122.5	165.4	251.8	227.7	96.6	233.5	214.2
32	13351	4616	1.117	84.7	114.0	164.4	165.5	62.3	155.5	145.2
33	2375	259	1.117	188.8	244.0	351.2	345.2	155.6	330.0	305.6
34	23956	24844	1.134	95.9	172.0	464.6	402.7	71.0	384.3	302.9

Test	Π_3	Π_2	θ radians	D_n microns	D_{VME} microns	D_{VH} microns	D_{MM} microns	D_{gN} microns	D_{gV} microns	D_{Saut} microns
40	7575	2484	1.134	101.2	149.5	287.7	252.8	83.4	251.9	216.6
41	8314	2405	0.663	130.1	247.4	579.1	555.0	86.4	512.2	433.5
42	8703	2518	1.920	155.3	226.4	408.1	372.4	119.9	363.9	318.9
48	8627	7895	1.117	83.9	109.6	172.2	157.3	70.5	156.1	140.5
49	450	266	1.152	121.9	193.2	380.8	365.6	90.2	338.9	292.8
51	75726	27767	1.134	93.9	150.3	335.2	290.0	70.7	281.8	233.7
53	7486	2588	1.152	80.2	105.6	166.0	153.8	66.0	150.4	135.8
54	4212	819	1.152	132.0	171.7	272.7	239.7	110.2	244.6	219.5
55	4222	461	1.117	184.0	310.7	671.9	628.4	135.0	592.0	500.9
56	13847	8281	1.134	105.9	180.9	424.5	375.1	78.5	360.6	297.9
57	13233	7914	0.663	93.0	138.7	267.6	238.7	73.4	233.7	201.1
58	13853	8285	1.920	112.3	173.2	320.3	298.8	81.5	287.2	252.7
59	7446	2506	0.663	114.3	194.4	423.7	379.3	80.8	369.3	313.0
60	7795	2623	1.920	153.8	227.1	433.6	373.3	117.7	377.0	325.0
62	2494	2633	1.117	81.3	102.0	141.0	134.5	67.2	132.8	124.1
63	7964	8408	1.169	112.2	172.5	334.1	308.8	87.5	296.1	255.8
64	1429	2671	1.117	100.8	139.0	229.5	213.9	80.8	207.8	185.9
65	2577	8652	1.169	121.0	167.7	289.1	266.2	98.0	257.9	227.3
66	1436	8582	1.117	65.8	86.5	134.6	122.7	54.2	122.3	110.8
67	7802	2625	1.169	116.2	170.4	310.0	291.1	90.9	276.5	241.9
68	7534	311	1.117	262.2	348.8	540.0	585.4	220.1	496.1	450.5
69	7513	604	1.117	127.1	165.2	258.6	225.8	104.8	233.8	210.5
70	13308	1901	1.152	92.3	123.4	197.4	178.8	74.3	178.4	160.4
71	7573	828	1.134	198.5	295.8	502.0	485.3	142.0	461.1	414.9
72	7575	2484	1.134	111.6	171.9	333.5	302.0	84.1	294.0	254.1

XVI. APPENDIX E. COMPUTED STATISTICS OF DISPERSION

Test	Π_3	Π_2	θ radians	s_N	s_V	s_{gN}	s_{gV}
4	23959.	2777.	1.1344	78.1	161.0	0.764	0.532
5	22897.	2654.	0.6632	112.9	268.7	0.792	0.577
6	23969.	2778.	1.9197	87.6	164.8	0.743	0.508
9	13464.	877.	1.1344	140.3	286.0	0.851	0.546
10	12867.	838.	0.6632	129.4	566.7	0.853	0.725
11	13470.	877.	1.9197	100.1	121.6	0.739	0.402
14	4222.	191.	1.1169	116.7	129.2	0.738	0.376
15	7514.	604.	1.1169	70.9	102.0	0.656	0.423
16	13353.	1908.	1.1169	51.1	95.5	0.758	0.492
18	13309.	1902.	1.1518	44.9	68.5	0.585	0.452
19	23761.	8708.	1.1169	68.3	142.4	0.690	0.525
20	23951.	8281.	1.1344	95.7	221.4	0.756	0.571
21	13478.	2622.	1.1344	93.7	147.8	0.800	0.458
22	13453.	2618.	1.1693	93.6	152.6	1.042	0.494
23	13495.	2626.	1.1693	78.7	160.6	1.000	0.521
24	13490.	2623.	3.4904	85.1	86.2	1.122	0.390
26	12247.	2383.	0.2443	97.5	297.2	0.762	0.653
27	12880.	2506.	0.6632	151.4	498.9	0.935	0.652
28	13965.	2717.	1.4136	134.5	291.2	0.569	0.556
29	13484.	2624.	1.9197	83.6	131.5	0.751	0.457
30	7574.	828.	1.1344	104.1	174.1	0.950	0.504
31	7514.	1462.	1.1169	78.1	98.8	0.754	0.398
32	13352.	4617.	1.1169	55.2	52.2	0.917	0.349
33	2375.	260.	1.1169	108.9	115.0	0.680	0.371
34	23956.	24844.	1.1344	87.2	266.9	0.759	0.656

Test	Π_3	Π_2	θ radians	s_N	s_V	s_{gN}	s_{gV}
40	7576.	2484.	1.1344	72.0	149.1	0.554	0.531
41	8314.	2406.	0.6632	134.1	269.5	0.905	0.530
42	8704.	2519.	1.9197	110.7	191.5	0.768	0.495
48	8628.	7895.	1.1169	48.3	76.8	0.625	0.450
49	450.	266.	1.1518	98.9	174.4	0.807	0.509
51	75727.	27767.	1.1344	75.5	204.0	0.774	0.600
53	7487.	2589.	1.1518	47.4	77.3	0.677	0.446
54	4213.	820.	1.1518	75.3	134.5	0.650	0.465
55	4222.	462.	1.1169	161.2	308.3	0.770	0.539
56	13848.	8281.	1.1344	93.1	248.5	0.757	0.591
57	13234.	7914.	0.6632	67.9	143.9	0.689	0.532
58	13854.	8285.	1.9197	89.2	147.2	0.848	0.484
59	7447.	2506.	0.6632	102.1	221.4	0.854	0.546
60	7796.	2624.	1.9197	111.3	237.1	0.786	0.536
62	2494.	2634.	1.1169	44.2	48.9	0.685	0.355
63	7964.	8409.	1.1693	86.4	159.1	0.673	0.514
64	1429.	2671.	1.1169	65.4	102.8	0.706	0.457
65	2578.	8653.	1.1693	78.2	138.2	0.683	0.490
66	1437.	8582.	1.1169	38.9	61.1	0.670	0.440
67	7803.	2626.	1.1693	83.3	145.8	0.723	0.496
68	7535.	312.	1.1169	159.5	218.3	0.444	0.425
69	7514.	604.	1.1169	72.6	117.5	0.670	0.454
70	13309.	1902.	1.1518	56.5	91.3	0.724	0.454
71	7574.	828.	1.1344	151.7	194.6	0.897	0.434
72	7576.	2484.	1.1344	86.7	165.7	0.781	0.519

XVII. APPENDIX F. COMPUTER PROGRAM FOR CALCULATION OF DIMENSIONLESS VARIABLES

```
C     THIS PROGRAM COMPUTES MEAN-DROP/ORIFICE RATIOS, WEBER NO.,REYNOLDS
C     NO., AND FAN ANGLE FROM DATA READ IN IN STATEMENTS 1 AND 2.
C
      WRITE (6,108)
    1 READ (5,109)N,DNTHE,DMN,VMD,VLD,DMM,XM,ZM,DSAUT
      IF(N - 99) 2,5,4
    2 READ (5,110) N1,P,A,THETA,VIS,SURFT,DENS
      IF (N1 - N) 4,3,4
    3 A = (A**0.5)*1000.
      DNTHE = DNTHE/A
      DMN = DMN/A
      VMD = VMD/A
      VLD = VLD/A
      DMM = DMM/A
      XM = XM/A
      ZM = ZM/A
      DSAUT = DSAUT/A
      THETA = THETA/57.3
      P =  68726.*P
      A = 0.0001*A
      W = A*P/SURFT
      R = (A*((P*DENS)**0.5))/VIS
      WRITE (6,112) N,R,W,THETA,DNTHE,DMN,VMD,VLD,DMM,XM,ZM,DSAUT
      DNTHE = DNTHE*1000.
      DMN = DMN*1000.
      VMD = VMD*1000.
      VLD = VLD*1000.
      DMM = DMM*1000.
      XM = XM*1000.
      ZM = ZM*1000.
      DSAUT = DSAUT*1000.
      THETA = THETA*1000.
```

```
      WRITE(4,113)  N,R,W,THETA,DNTHE,DMN,VMD,VLD,DMM,XM,ZM,DSAUT
      GO TO 1
    4 WRITE (6,111)
    5 STOP
  108 FORMAT (1H1,45X,18HTABULATED RESULTS ,//
     C   T2,'TEST',T10,'FB',T17,'WE',T25,'THETA',T34,'DNTHE/A',
     C   T43,'DMN/A',T52,'VMD/A',T61,'VLD/A',T70,'MMD/A',T79,'XM/A',
     C   T88,'ZM/A',T97 ,'DSAUT/A'/)
  109 FORMAT(I2,F6.1, 6X ,F6.1, 6X ,F6.1,F6.1, 6X ,F6.1,F6.1, 6X ,F6.1,
     C   6X ,F6.1)
  110 FORMAT(I2,8X,F6.1,7X,F6.4,5X,F5.1,5X,F6.4,8X,F4.1,4X,F5.3)
  111 FORMAT( 18HCARDS OUT OF ORDER)
  112 FORMAT (1X,I2,F8.0,F7.0,1X,9F9.4)
  113 FORMAT (I2,F7.0, F8.0,9F7.1)
      END
```

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C      THIS PROGRAM COMPUTES COEFFICIENT OF VARIATION, WEBER NO.,REYNOLDS
C      NO., AND FAN ANGLE FROM DATA READ IN IN STATEMENTS 1 AND 2.
C
       WRITE (6,108)
     1 READ (5,109)N,DNTHE,SDTHE,DMN,SDN,VLD,SDV,XSD,ZSD
       IF(N - 99) 2,5,4
     2 READ (5,110) N1,P,A,THETA,VIS,SURFT,DENS
       IF (N1 - N) 4,3,4
     3 A = (A**0.5)*0.1
       CVN = SDN/DMN
       CVV = SDV/VLD
       CVTHE = SDTHE/DNTHE
       THETA = THETA/57.3
       P =  68726.*P
       R = (A*((P*DENS)**0.5))/VIS
       W = A*P/SURFT
       WRITE (6,112) N,R,W,THETA,CVTHE,CVN,CVV,XSD,ZSD
       DNTHE = DNTHE*1000.
       CVV = CVV * 1000.
       CVTHE = CVTHE * 1000.
       CVN = CVN * 1000.
       XSD = XSD * 1000.
       ZSD= ZSD * 1000.
       THETA = THETA*1000.
       WRITE(4,113)  N,R,W,THETA,CVTHE,CVN,CVV,XSD,ZSD
       GO TO 1
     4 WRITE (6,111)
     5 STOP
   108 FORMAT (1H1,45X,18HTABULATED RESULTS ,//
      C  T2,'TEST',T10,'RE',T17,'WE',T25,'THETA',T34,'CVTHE',T43,'CVN',
      CT52,'CVV',T61, 'XSD',T70,'ZSD',/)
   109 FORMAT(I2,F6.1,F6.1,F6.1,F6.1,F6.1,6X,F6.1,12X,F6.3,6X,F6.3)
   110 FORMAT(I2,8X,F6.1,7X,F6.4,5X,F5.1,5X,F6.4,8X,F4.1,4X,F5.3)
   111 FORMAT( 18HCARDS OUT OF ORDER)
   112 FORMAT (1X,I2,F8.0,F7.0,1X,9F9.4)
   113 FORMAT (I2,F7.0, F8.0,9F7.1)
       END
```

XVIII. APPENDIX G. CENTRAL TENDENCY STATISTICS IN DIMENSIONLESS FORM

Test	Π_3	Π_2	θ microns	$D_n/A^{1/2}$	$D_{VME}/A^{1/2}$	$D_{VH}/A^{1/2}$	$D_{MM}/A^{1/2}$
4	23959.	2777.	1.1344	0.1050	0.1613	0.3174	0.2850
5	22897.	2654.	0.6632	0.1325	0.2350	0.5582	0.5154
6	23969.	2778.	1.9197	0.1362	0.1918	0.3405	0.3024
9	13464.	877.	1.1344	0.1538	0.2761	0.6368	0.6238
10	12867.	838.	0.6632	0.1373	0.2756	0.9179	0.7731
11	13470.	877.	1.9197	0.1676	0.2240	0.3404	0.3312
14	4222.	191.	1.1169	0.6526	0.8501	1.2325	1.2090
15	7514.	604.	1.1169	0.4171	0.5365	0.8064	0.7181
16	13353.	1908.	1.1169	0.2616	0.3609	0.6159	0.5474
18	13309.	1902.	1.1518	0.2496	0.3312	0.5283	0.4885
19	23761.	8708.	1.1169	0.3050	0.4571	0.8759	0.7892
20	23951.	8281.	1.1344	0.1106	0.1913	0.4409	0.3999
21	13478.	2622.	1.1344	0.1330	0.1945	0.3359	0.3137
22	13453.	2618.	1.1693	0.1069	0.1812	0.3643	0.3472
23	13495.	2626.	1.1693	0.0960	0.1548	0.3081	0.2726
24	13490.	2623.	3.4904	0.0919	0.1572	0.2805	0.2897
26	12247.	2383.	0.2443	0.1239	0.2207	0.5928	0.5226
27	12880.	2506.	0.6632	0.1501	0.3136	0.9570	0.8442
28	13965.	2717.	1.4136	0.1715	0.2691	0.5587	0.5070
29	13484.	2624.	1.9197	0.1338	0.1838	0.3016	0.2762
30	7574.	828.	1.1344	0.1260	0.2062	0.4121	0.3926
31	7514.	1462.	1.1169	0.2279	0.3078	0.4686	0.4237
32	13352.	4617.	1.1169	0.1576	0.2121	0.3059	0.3080
33	2375.	260.	1.1169	0.6245	0.8071	1.1617	1.1418
34	23956.	24844.	1.1344	0.0995	0.1784	0.4819	0.4177

Test	Π_3	Π_2	θ radians	$D_{gN}/A^{1/2}$	$D_{gV}/A^{1/2}$	$D_{Saut}/A^{1/2}$
4	23959.	2777.	1.1344	0.0797	0.2775	0.2387
5	22897.	2554.	0.6632	0.0955	0.4812	0.3983
6	23969.	2778.	1.9197	0.1076	0.3008	0.2632
9	13464.	877.	1.1344	0.1081	0.5601	0.4695
10	12867.	838.	0.6632	0.0955	0.7245	0.5428
11	13470.	877.	1.9197	0.1340	0.3160	0.2891
14	4222.	191.	1.1169	0.5246	1.1544	1.0684
15	7514.	604.	1.1169	0.3473	0.7393	0.6741
16	13353.	1908.	1.1169	0.2064	0.5464	0.4833
18	13309.	1902.	1.1518	0.2094	0.4799	0.4308
19	23761.	8708.	1.1169	0.2388	0.7671	0.6632
20	23951.	8281.	1.1344	0.0812	0.3809	0.3170
21	13478.	2622.	1.1344	0.1003	0.3039	0.2712
22	13453.	2618.	1.1693	0.0690	0.3269	0.2841
23	13495.	2626.	1.1693	0.0644	0.2699	0.2338
24	13490.	2623.	0.4904	0.0548	0.2630	0.2394
26	12247.	2383.	0.2443	0.0922	0.4913	0.3873
27	12880.	2566.	0.6632	0.0985	0.7963	0.6222
28	13965.	2717.	1.4136	0.1353	0.4846	0.4100
29	13484.	2624.	1.9197	0.1056	0.2729	0.2446
30	7574.	828.	1.1344	0.0869	0.3686	0.3187
31	7514.	1462.	1.1169	0.1798	0.4345	0.3986
32	13352.	4617.	1.1169	0.1159	0.2894	0.2702
33	2375.	260.	1.1169	0.5147	1.0915	1.0108
34	23956.	24344.	1.1344	0.0737	0.3987	0.3142

Test	Π_3	Π_2	θ microns	$D_n/A^{1/2}$	$D_{VME}/A^{1/2}$	$D_{VH}/A^{1/2}$	$D_{MM}/A^{1/2}$
40	7576.	2484.	1.1344	0.1050	0.1551	0.2984	0.2622
41	8314.	2406.	0.6632	0.1412	0.2685	0.6286	0.6024
42	8704.	2519.	1.9197	0.1610	0.2348	0.4232	0.3861
48	8628.	7895.	1.1169	0.2775	0.3625	0.5696	0.5203
49	450.	266.	1.1518	0.4045	0.6412	1.2637	1.2133
51	75727.	27767.	1.1344	0.0974	0.1559	0.3477	0.3008
53	7487.	2589.	1.1518	0.2662	0.3504	0.5509	0.5104
54	4213.	820.	1.1518	0.4381	0.5698	0.9050	0.7955
55	4222.	462.	1.1169	0.3424	0.5782	1.2503	1.1693
56	13848.	8281.	1.1344	0.1099	0.1877	0.4404	0.3891
57	13234.	7914.	0.6632	0.1009	0.1506	0.2905	0.2591
58	13854.	8285.	1.9197	0.1164	0.1796	0.3321	0.3098
59	7447.	2506.	0.6632	0.1241	0.2110	0.4599	0.4117
60	7796.	2624.	1.9197	0.1595	0.2355	0.4496	0.3871
62	2494.	2634.	1.1169	0.2689	0.3374	0.4664	0.4449
63	7964.	8409.	1.1693	0.1162	0.1787	0.3461	0.3199
64	1429.	2671.	1.1169	0.3334	0.4598	0.7591	0.7075
65	2578.	8653.	1.1693	0.1254	0.1737	0.2995	0.2758
66	1437.	8582.	1.1169	0.2176	0.2861	0.4452	0.4059
67	7803.	2626.	1.1693	0.1204	0.1765	0.3212	0.3016
68	7535.	312.	1.1169	0.8673	1.1537	1.7862	1.9363
69	7514.	604.	1.1169	0.4204	0.5464	0.8554	0.7469
70	13309.	1902.	1.1518	0.3063	0.4095	0.6551	0.5934
71	7574.	828.	1.1344	0.2059	0.3068	0.5207	0.5045
72	7576.	2484.	1.1344	0.1158	0.1783	0.3460	0.3133

Test	Π_3	Π_2	θ radians	$D_{gN}/A^{1/2}$	$D_{gV}/A^{1/2}$	$D_{Saut}/A^{1/2}$
40	7576.	2484.	1.1344	0.0865	0.2613	0.2247
41	8314.	2406.	0.6632	0.0938	0.5560	0.4706
42	8704.	2519.	1.9197	0.1243	0.3773	0.3307
48	8628.	7895.	1.1169	0.2332	0.5163	0.4647
49	450.	266.	1.1518	0.2993	1.1247	0.9717
51	75727.	27767.	1.1344	0.0733	0.2923	0.2424
53	7487.	2589.	1.1518	0.2190	0.4991	0.4507
54	4213.	820.	1.1518	0.3657	0.8117	0.7284
55	4222.	462.	1.1169	0.2512	1.1016	0.9321
56	13846.	3281.	1.1344	0.0814	0.3741	0.3090
57	13234.	7914.	0.6632	0.0797	0.2537	0.2183
58	13854.	8285.	1.9197	0.0845	0.2978	0.2620
59	7447.	2506.	0.6632	0.0877	0.4009	0.3398
60	7796.	2624.	1.9197	0.1220	0.3909	0.3370
62	2494.	2624.	1.1169	0.2223	0.4393	0.4105
63	7964.	3409.	1.1693	0.0907	0.3068	0.2650
64	1429.	2071.	1.1169	0.2673	0.6873	0.6149
65	2578.	3053.	1.1693	0.1015	0.2672	0.2355
66	1437.	8582.	1.1169	0.1793	0.4045	0.3665
67	7803.	2626.	1.1693	0.0942	0.2865	0.2506
68	7535.	312.	1.1169	0.7280	1.6410	1.4901
69	7514.	604.	1.1169	0.3466	0.7733	0.6963
70	13309.	1902.	1.1518	0.2466	0.5920	0.5323
71	7574.	828.	1.1344	0.1473	0.4783	0.4304
72	7576.	2484.	1.1344	0.0872	0.3050	0.2636

XVIX. APPENDIX H. DISPERSION STATISTICS IN DIMENSIONLESS FORM

Test	Π_2	Π_3	θ radians	s_N/D_N	s_{VH}/D_{VH}	s_{gN}	s_{gV}
4	2777	23959	1.1344	0.7717	1.0354	0.7640	0.5320
5	2654	22897	0.6632	0.9247	1.2411	0.7920	0.5770
6	2778	23969	1.9197	0.6667	0.8908	0.7430	0.5080
9	877	13464	1.1344	0.9461	1.0744	0.8510	0.5460
10	838	12867	0.6632	1.0229	2.2320	0.8530	0.7250
11	577	13470	1.9197	0.6194	0.5630	0.7390	0.4020
14	191	4222	1.1169	0.5915	0.5027	0.7380	0.3760
15	604	7514	1.1169	0.5623	0.6289	0.6560	0.4230
16	1908	13353	1.1169	0.6460	0.8753	0.7580	0.4920
18	1902	13319	1.1518	0.5971	0.6864	0.5850	0.4520
19	4708	23761	1.1169	0.7408	1.0304	0.6900	0.5250
20	5281	23951	1.1344	0.8977	1.2007	0.7560	0.5710
21	2622	13478	1.1344	0.7309	0.7883	0.8000	0.4580
22	2618	13457	1.1693	0.9096	0.8755	1.0420	0.4940
23	2626	13495	1.1693	0.8490	1.0750	1.0000	0.5210
24	2623	13490	3.4904	0.9605	0.5686	1.1220	0.3900
26	2383	12247	[illegible].2443	0.8986	1.5375	0.7620	0.6530
27	2506	12880	0.6632	1.0947	1.7269	0.9350	0.6520
28	2717	13965	1.4136	0.7852	1.0833	0.5690	0.5560
29	2624	13484	1.9197	0.6481	0.7417	0.7510	0.4570
30	828	7574	1.1344	0.8568	0.8758	0.9500	0.5040
31	1362	7514	1.1169	0.6376	0.5973	0.7540	0.3980
32	4617	13252	1.1169	0.6517	0.4579	0.9170	0.3490
33	261	2375	1.1169	0.5768	0.4713	0.6800	0.3710
34	24844	23956	1.1344	0.9093	1.5517	0.7590	0.6560

Test	Π_2	Π_3	θ radians	s_N/D_N	s_{VH}/D_{VH}	s_{gN}	s_{gV}
40	2484	7576	1.1344	0.7115	0.9973	0.5540	0.5310
41	2466	8314	0.6632	1.0307	1.0893	0.9050	0.5300
42	2519	8704	1.9197	0.7128	0.8458	0.7680	0.4950
48	7396	8628	1.1169	0.5757	0.7007	0.6250	0.4500
49	266	451	1.1518	0.8113	0.9027	0.8070	0.5090
51	27767	75727	1.1344	0.8040	1.3573	0.7740	0.6000
53	2569	7487	1.1518	0.5910	0.7320	0.6770	0.4460
54	821	4215	1.1518	0.5705	0.7833	0.6500	0.4650
55	462	4222	1.1169	0.8761	0.9923	0.7700	0.5390
56	8281	13849	1.1344	0.8791	1.3737	0.7570	0.5910
57	7914	13234	0.6632	0.7301	1.0375	0.6890	0.5320
58	8265	13854	1.9197	0.7943	0.8499	0.8480	0.4840
59	2506	74471	0.6632	0.8933	1.1389	0.8540	0.5460
60	2524	7796	1.9197	0.7237	1.0449	0.7860	0.5360
62	2634	2494	1.1169	0.5437	0.4794	0.6850	0.3550
63	8409	7464	1.1693	0.7701	0.9223	0.6730	0.5140
64	2671	1429	1.1169	0.6488	0.7396	0.7060	0.4570
65	3652	2576	1.1693	0.6463	0.8241	0.6830	0.4900
66	8582	1437	1.1169	0.5912	0.7064	0.6700	0.4400
67	2676	7853	1.1693	0.7169	0.8556	0.7230	0.4960
68	312	7535	1.1169	0.6083	0.6259	0.4440	0.4250
69	604	7514	1.1169	0.5712	0.7113	0.6700	0.4540
70	1902	13309	1.1518	0.6121	0.7399	0.7240	0.4540
71	828	7574	1.1344	0.7642	0.6579	0.8970	0.4340
72	2484	7576	1.1344	0.7769	0.9639	0.7810	0.5190

XX. APPENDIX I. PRELIMINARY PLOTS OF $\overline{D}/A^{1/2}$ AGAINST $p\ A^{1/2}/\sigma$ AT VARYING LEVELS OF $p^{1/2}A^{1/2}\rho^{1/2}/\mu$

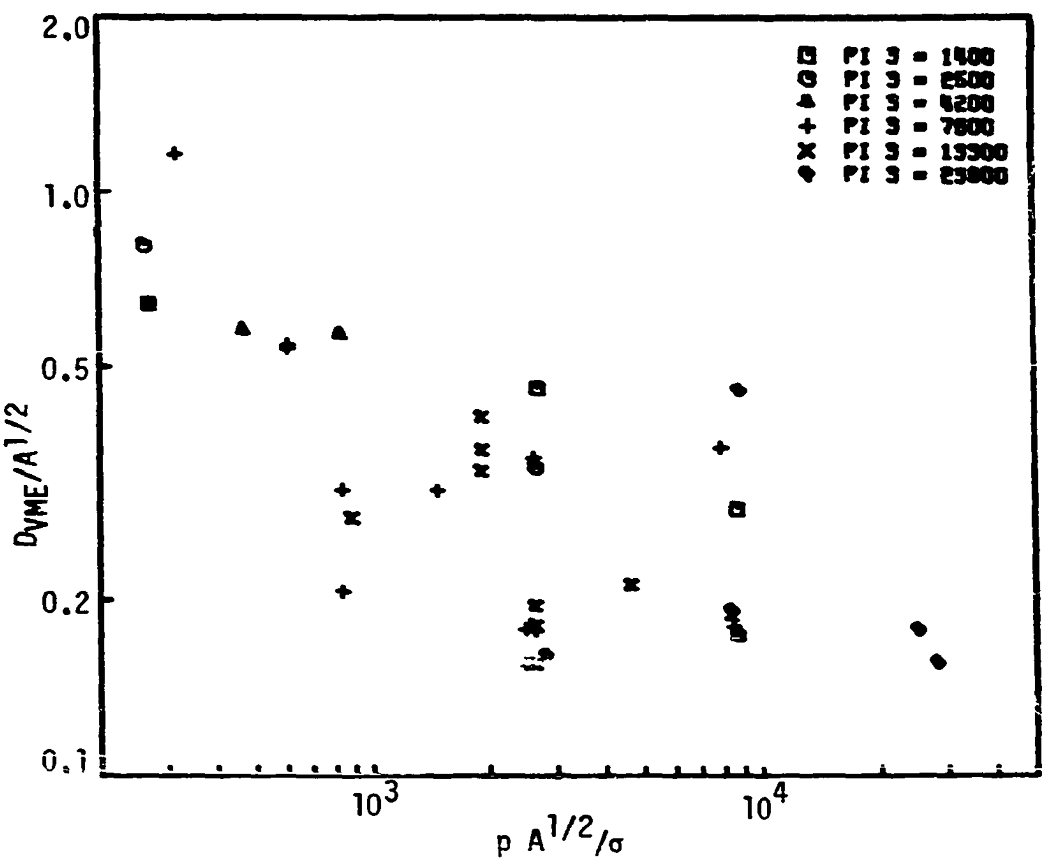

Figure 51. $D_{VME}/A^{1/2}$ as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$

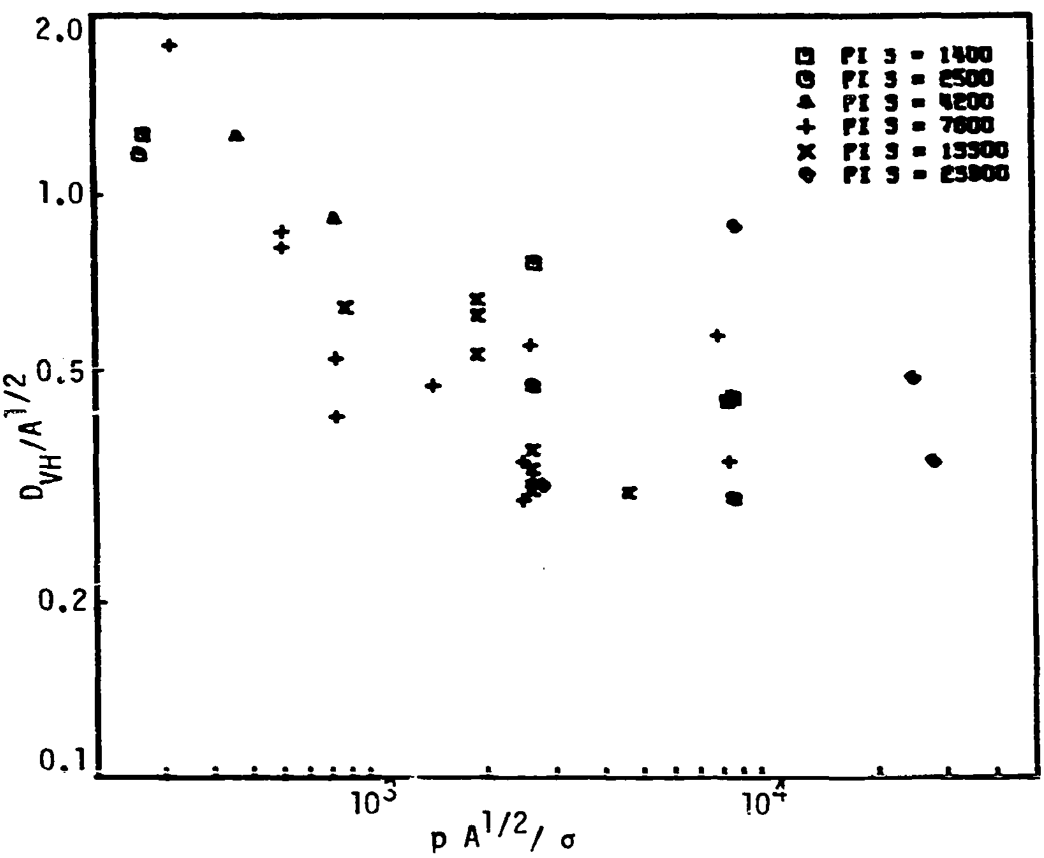

Figure 52. $D_{VH}/A^{1/2}$ as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at different levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$

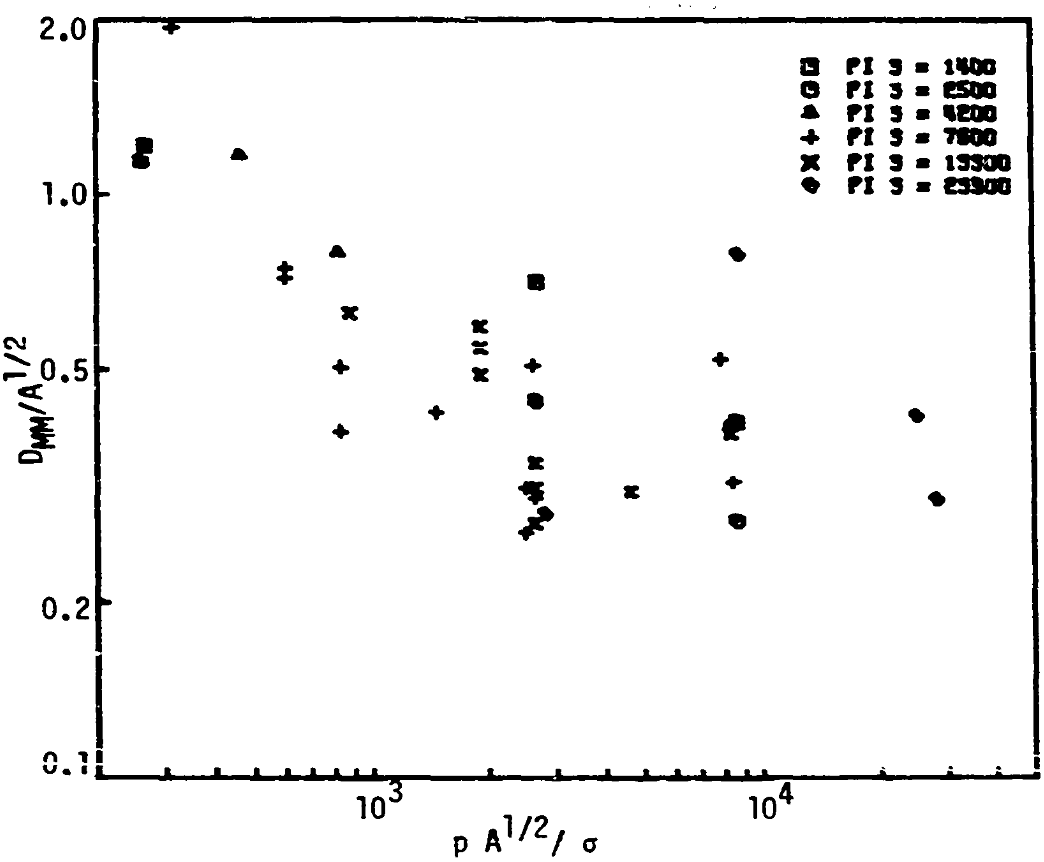

Figure 53. $D_{MM}/A^{1/2}$ as a function of $p\,A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$

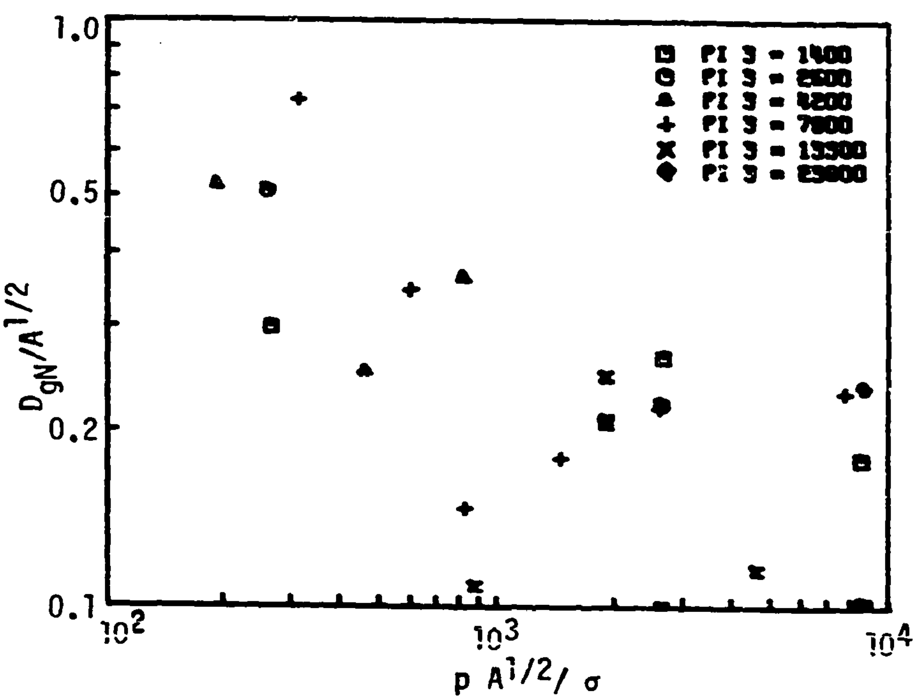

Figure 54. $D_{gN}/A^{1/2}$ as a function of $p\ A^{1/2}/\sigma$ for 65° nominal fan angle nozzles, at differing levels of $p^{1/2}A^{1/2}\rho^{1/2}/\mu$